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PTO/SB/05 (4/98)
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UTILITY PATENT APPLICATION TRANSMITTAL

(Only for new nonprovisional applications under 37 C.F.R. § 1.53(b))

Attorney Docket No.

First Inventor or Application Identifier EDELSON, Jonathan

Title Electronically Controlled Engine

Express Mail Label No. EJ764962840US

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APPLICATION ELEMENTS

See MPEP chapter 600 concerning utility patent application contents.

1. ☒ * Fee Transmittal Form (e.g., PTO/SB/17)
(Submit an original and a duplicate for fee processing)
2. ☒ Specification [Total Pages 75]
(preferred arrangement set forth below)
 - Descriptive title of the invention
 - Cross References to Related Applications
 - Statement Regarding Fed sponsored R & D
 - Reference to Microfiche Appendix
 - Background of the invention
 - Brief Summary of the invention
 - Brief Description of the Drawings (if filed)
 - Detailed Description
 - Claim(s)
 - Abstract of the Disclosure
3. ☒ Drawing(s) (35 U.S.C. 113) [Total Sheets 9]
4. Oath or Declaration [Total Pages 2]
 - a. ☒ Newly executed (original or copy)
 - b. ☐ Copy from a prior application (37 C.F.R. § 1.63(d))
(for continuation/divisional with Box 16 completed)
 - i. ☐ DELETION OF INVENTOR(S)
Signed statement attached deleting inventor(s) named in the prior application, see 37 C.F.R. §§ 1.63(d)(2) and 1.33(b).

* NOTE FOR ITEMS 1 & 13: IN ORDER TO BE ENTITLED TO PAY SMALL ENTITY FEES, A SMALL ENTITY STATEMENT IS REQUIRED (37 C.F.R. § 1.27), EXCEPT IF ONE FILED IN A PRIOR APPLICATION IS RELIED UPON (37 C.F.R. § 1.28).

ADDRESS TO:

Assistant Commissioner for Patents
Box Patent Application
Washington, DC 20231

5. ☐ Microfiche Computer Program (Appendix)
6. Nucleotide and/or Amino Acid Sequence Submission
(if applicable, all necessary)
 - a. ☐ Computer Readable Copy
 - b. ☐ Paper Copy (identical to computer copy)
 - c. ☐ Statement verifying identity of above copies

ACCOMPANYING APPLICATION PARTS

7. ☐ Assignment Papers (cover sheet & document(s))
8. ☐ 37 C.F.R. § 3.73(b) Statement of Power of Attorney
(when there is an assignee)
9. ☐ English Translation Document (if applicable)
10. ☐ Information Disclosure Statement (IDS)/PTO-1449
Copies of IDS Citations
11. ☐ Preliminary Amendment
12. ☒ Return Receipt Postcard (MPEP 503)
(Should be specifically itemized)
13. ☒ * Small Entity Statement(s) filed in prior application,
(PTO/SB/09-12) Status still proper and desired
14. ☐ Certified Copy of Priority Document(s)
(if foreign priority is claimed)
15. ☐ Other:

16. If a CONTINUING APPLICATION, check appropriate box, and supply the requisite information below and in a preliminary amendment:

☐ Continuation ☐ Divisional ☐ Continuation-in-part (CIP) of prior application No. _____

Prior application information: Examiner _____ Group / Art Unit: _____

For CONTINUATION or DIVISIONAL APPS only: The entire disclosure of the prior application, from which an oath or declaration is supplied under Box 4b, is considered a part of the disclosure of the accompanying continuation or divisional application and is hereby incorporated by reference. The incorporation can only be relied upon when a portion has been inadvertently omitted from the submitted application parts.

17. CORRESPONDENCE ADDRESS

☐ Customer Number or Bar Code Label or ☒ Correspondence address below

(Insert Customer No. or Attach bar code label here)

Name	Borealis Technical Limited				
Address	23545 NW Skyline Blvd				
City	North Plains	State	OR	Zip Code	97133-9204
Country	US	Telephone	503-621-3286	Fax	503-621-3425

Name (Print/Type)	Jonathan Sidney Edelson	Registration No. (Attorney/Agent)	
Signature	<i>Jonathan Edelson</i>	Date	09/28/2000

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Patent fees are subject to annual revision
Small Entity payments must be supported by a small entity statement,
otherwise large entity fees must be paid. See Forms PTO/SB/09-12
See 37 C.F.R. §§ 1.27 and 1.28.

TOTAL AMOUNT OF PAYMENT (\$) 2,319.00

Complete if Known

Application Number
Filing Date 09/28/2000
First Named Inventor EDELSON, Jonathan
Examiner Name
Group / Art Unit
Attorney Docket No.

METHOD OF PAYMENT (check one)

1. ☐ The Commissioner is hereby authorized to charge indicated fees and credit any overpayments to:

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Deposit Account Name

☐ Charge Any Additional Fee Required
Under 37 CFR §§ 1.16 and 1.17

2. ☒ Payment Enclosed:
☒ Check ☐ Money Order ☐ Other

FEE CALCULATION

1. BASIC FILING FEE

Large Entity Fee Code (\$)	Small Entity Fee Code (\$)	Fee Description	Fee Paid
101 690	201 345	Utility filing fee	345
106 310	206 155	Design filing fee	
107 480	207 240	Plant filing fee	
108 690	208 345	Reissue filing fee	
114 150	214 75	Provisional filing fee	

SUBTOTAL (1) (\$) 345

2. EXTRA CLAIM FEES

Total Claims	Extra Claims	Fee from below	Fee Paid
222	202	9	1818
Independent Claims 7	3	4	156
Multiple Dependent			

**or number previously paid, if greater; For Reissues, see below

Large Entity Fee Code (\$)	Small Entity Fee Code (\$)	Fee Description
103 18	203 9	Claims in excess of 20
102 78	202 39	Independent claims in excess of 3
104 260	204 130	Multiple dependent claim, if not paid
109 78	209 39	** Reissue independent claims over original patent
110 18	210 9	** Reissue claims in excess of 20 and over original patent

SUBTOTAL (2) (\$) 1974

FEE CALCULATION (continued)

3. ADDITIONAL FEES

Large Entity Fee Code (\$)	Small Entity Fee Code (\$)	Fee Description	Fee Paid
105 130	205 65	Surcharge - late filing fee or oath	
127 50	227 25	Surcharge - late provisional filing fee or cover sheet	
139 130	139 130	Non-English specification	
147 2,520	147 2,520	For filing a request for reexamination	
112 920*	112 920*	Requesting publication of SIR prior to Examiner action	
113 1,840*	113 1,840*	Requesting publication of SIR after Examiner action	
115 110	215 55	Extension for reply within first month	
116 380	216 190	Extension for reply within second month	
117 870	217 435	Extension for reply within third month	
118 1,360	218 680	Extension for reply within fourth month	
128 1,850	228 925	Extension for reply within fifth month	
119 300	219 150	Notice of Appeal	
120 300	220 150	Filing a brief in support of an appeal	
121 260	221 130	Request for oral hearing	
138 1,510	138 1,510	Petition to institute a public use proceeding	
140 110	240 55	Petition to revive - unavoidable	
141 1,210	241 605	Petition to revive - unintentional	
142 1,210	242 605	Utility issue fee (or reissue)	
143 430	243 215	Design issue fee	
144 580	244 290	Plant issue fee	
122 130	122 130	Petitions to the Commissioner	
123 50	123 50	Petitions related to provisional applications	
126 240	126 240	Submission of Information Disclosure Stmt	
581 40	581 40	Recording each patent assignment per property (times number of properties)	
146 690	246 345	Filing a submission after final rejection (37 CFR § 1.129(a))	
149 690	249 345	For each additional invention to be examined (37 CFR § 1.129(b))	

Other fee (specify) _____

Other fee (specify) _____

* Reduced by Basic Filing Fee Paid

SUBTOTAL (3) (\$) _____

SUBMITTED BY

Name (Print/Type) Jonathan Edelson

Signature

Registration No.
(Attorney/Agent)

Complete (if applicable)

Telephone 503-621-3286

Date 09/28/2000

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STATEMENT CLAIMING SMALL ENTITY STATUS
(37 CFR 1.9(f) & 1.27(c))--SMALL BUSINESS CONCERN

Docket Number (Optional)

Applicant, Patentee, or Identifier: EDELSON, Jonathan Sidney

Application or Patent No.: _____

Filed or Issued: 09/28/2000

Title: ELECTRONICALLY CONTROLLED ENGINE GENERATOR SET

I hereby state that I am

- ☐ the owner of the small business concern identified below:
☒ an official of the small business concern empowered to act on behalf of the concern identified below:

NAME OF SMALL BUSINESS CONCERN Borealis Technical Limited

ADDRESS OF SMALL BUSINESS CONCERN Suite 3C, Centre Plaza,
Horse Barrack Lane, PO Box 926, Gibraltar

I hereby state that the above identified small business concern qualifies as a small business concern as defined in 13 CFR Part 121 for purposes of paying reduced fees to the United States Patent and Trademark Office, in that the number of employees of the concern, including those of its affiliates, does not exceed 500 persons. For purposes of this statement, (1) the number of employees of the business concern is the average over the previous fiscal year of the concern of the persons employed on a full-time, part-time, or temporary basis during each of the pay periods of the fiscal year, and (2) concerns are affiliates of each other when either, directly or indirectly, one concern controls or has the power to control the other, or a third party or parties controls or has the power to control both.

I hereby state that rights under contract or law have been conveyed to and remain with the small business concern identified above with regard to the invention described in:

- ☒ the specification filed herewith with title as listed above.
☐ the application identified above.
☐ the patent identified above.

If the rights held by the above identified small business concern are not exclusive, each individual, concern, or organization having rights in the invention must file separate statements as to their status as small entities, and no rights to the invention are held by any person, other than the inventor, who would not qualify as an independent inventor under 37 CFR 1.9(c) if that person made the invention, or by any concern which would not qualify as a small business concern under 37 CFR 1.9(d), or a nonprofit organization under 37 CFR 1.9(e).

- Each person, concern, or organization having any rights in the invention is listed below:
☒ no such person, concern, or organization exists.
☐ each such person, concern, or organization is listed below.

Separate statements are required from each named person, concern or organization having rights to the invention stating their status as small entities. (37 CFR 1.27)

I acknowledge the duty to file, in this application or patent, notification of any change in status resulting in loss of entitlement to small entity status prior to paying, or at the time of paying, the earliest of the issue fee or any maintenance fee due after the date on which status as a small entity is no longer appropriate. (37 CFR 1.28(b))

NAME OF PERSON SIGNING Rodney T. Cox

TITLE OF PERSON IF OTHER THAN OWNER CEO, Chairman

ADDRESS OF PERSON SIGNING 51 Heathway Court, London NW3 7TS, England

SIGNATURE [Signature] DATE 09/28/2000

**STATEMENT CLAIMING SMALL ENTITY STATUS
(37 CFR 1.9(f) & 1.27(b))--INDEPENDENT INVENTOR**

Docket Number (Optional)

Applicant, Patentee, or Identifier: EDELSON, Jonathan Sidney

Application or Patent No.: _____

Filed or Issued: September 28, 2000

Title: ELECTRONICALLY CONTROLLED ENGINE GENERATOR SET

As a below named inventor, I hereby state that I qualify as an independent inventor as defined in 37 CFR 1.9(c) for purposes of paying reduced fees to the Patent and Trademark Office described in:

- ☒ the specification filed herewith with title as listed above.
☐ the application identified above.
☐ the patent identified above.

I have not assigned, granted, conveyed, or licensed, and am under no obligation under contract or law to assign, grant, convey, or license, any rights in the invention to any person who would not qualify as an independent inventor under 37 CFR 1.9(c) if that person had made the invention, or to any concern which would not qualify as a small business concern under 37 CFR 1.9(d) or a nonprofit organization under 37 CFR 1.9(e).

Each person, concern, or organization to which I have assigned, granted, conveyed, or licensed or am under an obligation under contract or law to assign, grant, convey, or license any rights in the invention is listed below:

- ☐ No such person, concern, or organization exists.
☒ Each such person, concern, or organization is listed below.

Borealis Technical Limited

Separate statements are required from each named person, concern, or organization having rights to the invention stating their status as small entities. (37 CFR 1.27)

I acknowledge the duty to file, in this application or patent, notification of any change in status resulting in loss of entitlement to small entity status prior to paying, or at the time of paying, the earliest of the issue fee or any maintenance fee due after the date on which status as a small entity is no longer appropriate. (37 CFR 1.28(b))

Jonathan Sidney Edelson

NAME OF INVENTOR

NAME OF INVENTOR

NAME OF INVENTOR

Jonathan Edelson
Signature of inventor

Signature of inventor

Signature of inventor

09/28/2000

Date

Date

Date

Patent application of
Jonathan Sidney Edelson
for

ELECTRONICALLY CONTROLLED ENGINE GENERATOR SET

5

CROSS REFERENCE TO RELATED APPLICATION

This application claims priority from, and incorporates by reference in its entirety, U.S. Provisional Application No. 60/156,402, filed on September 28, 1999.

10

TECHNICAL FIELD OF THE INVENTION

The present invention is related to the field of electric power production using combustion engines. It is further related to methods of control of electric power systems responding to load changes.

15

BACKGROUND OF THE INVENTION

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In an engine/generator system, the fuel supply to the prime mover is directly controlled by an actuator means, generally with a throttle or injection pump. Fuel supply adjustment is a method of adjusting the torque/speed characteristics of the prime mover. As the throttle is closed or the fuel injection setting reduced, the torque produced at a given rotational velocity is similarly reduced, causing the system to slow down, while wide open throttle maximizes the torque and power output at a given speed. In conventional engine/generator systems, the speed of the system is controlled by altering the torque/speed characteristic of the prime mover. This results in engine inefficiency.

25

An additional cause of engine inefficiency is friction. As the piston moves through the cylinder, work must be done because of friction between the piston and the cylinder. Every time the piston moves through a stroke, some energy is lost, regardless of engine power output for that piston stroke. The greater the energy output per piston stroke, the less energy lost to friction as compared to energy output.

30

Other sources of engine inefficiency are parasitic loads such as oil pumps and the like, which vary with engine speed, but not power output. The higher the RPM of the engine, the more energy lost to these loads, regardless

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of actual engine power output. Parasitic loads and cylinder friction mean that for constant power output, lower RPM will generally be more efficient.

BACKGROUND HYBRID ELECTRIC VEHICLES

A partial solution for inefficiency during low demand is found in systems comprising an energy storage unit (such as a battery) besides the engine-generator system. An example for such system is the Hybrid Electric Vehicle (HEV), in which the solution for the inefficient low load mode is simply to turn the engine and generator off. The power demand is supplied by the battery until a higher demand is required or until the battery reaches a low energy level. The engine and the generator are then turned on to recharge the battery and to supply power, directly or via the battery, to the vehicle.

Attempts to deal with engine inefficiency, such as with the hybrid electric vehicle have not been successful. HEVs have a problem in that involved in their usage is a substantial amount of restarting of the engine and generator, which releases fumes and is a particularly inefficient period in engine operation. Secondly, when the engine is turned off, a great amount of inertial energy is lost. This results in a waste of energy, invested in regaining the inertial energy, when the engine is restarted. Third, no currently available energy storage system is perfect; more energy must be supplied to the energy storage system than is later removed as useable electricity, with the difference being lost as heat. Energy storage systems also have limited life, in terms of number of charge/discharge cycles, and aging due to deep discharge. Even in the hybrid electric vehicle, there is substantial utility to a wide range of generator power output, providing efficiency can be maintained over this range.

BACKGROUND ELECTRICAL POWER CONVERSION

Methods for the conversion of electrical power at a given voltage, current, and frequency, to electrical power at a different voltage, current, or frequency are well known in the art. The simplest device, the transformer, is used to trade voltage for current with little loss of power to inefficiency.

Other devices convert input electrical power to an output electrical power via intermediate mechanical form, or from alternating current to alternating current of different characteristics via intermediate direct current. Power electronics are devices that usually contain transistors or

similar components, and use switches to vary the electrical characteristics of their output, according to requirements. These include many variations, some of which are the bipolar transistor, the darlington pair of transistors, the field effect transistor, the pulse width modulated DC controller, the
5 Silicon Controlled Rectifier, the DC link converter, the insulated gate bipolar transistor, the silicon controlled rectifier, the MOS controlled thyristor, as well as optically driven devices, vacuum devices, gas filled devices, and even mechanical devices. Power electronic devices can often act as variable pseudo-resistance, that is they can create voltage/current output
10 relationships without dissipating power in the fashion of an actual resistor. The Silicon Controlled Rectifier can control how much AC power is delivered to a load.

BACKGROUND ELECTRIC GENERATORS' CONTROL APPARATUS

15 Electric control systems for generators are well known in the field of the art. Output of a desired frequency, voltage and current can either be achieved by controlling the operational state of the generator, or by converting the native output power of the generator to the desired voltage, frequency, current, or otherwise characterized output power.

20 Output characteristics of a generator are not independent, and are related by load considerations and generator internal characteristics. For example, a DC generator feeding a resistive load, when under circumstances that increase the output voltage of the generator, will also experience an increase in current flow. Often various changes in output are described with
25 other output aspects held constant.

ENGINE-GENERATOR SYSTEMS AND POWER EQUILIBRIUM

Engine-generator systems, in which an engine is directly mechanically linked to a generator, and providing the generator with power in the forms of
30 torque and speed, turn at a fixed speed relation. Torque supplied by the engine is not necessarily equal to the torque absorbed by the generator. If, due to some perturbation, the generator is unable to absorb all the torque that the prime mover provides, a potentially dangerous situation may arise, for the system is not operating in equilibrium. Usually, it is the speed of
35 the engine, and with it, the speed of the generator, which will change when

the system is not operating in equilibrium, and in the case mentioned above, the speed of the system will probably increase. Sometimes the fixed mechanical linkage between the engine and generator includes some sort of gearing or mechanical advantage. In this case, then when the system is
5 operating in equilibrium, there will be an equilibrium between the individual linkages between motor and gearing mechanism, and between gearing mechanism and generator.

The term "torque load", in the course of this specification, is used to mean the amount of torque which the generator absorbs from the engine or
10 other prime mover, to which it is connected. It is also described as the torque in the direction counter to rotation that the generator applies to a transmission with the prime mover. A negative torque load would refer to a torque in the direction of rotation (i.e. the generator acting as a motor). The "torque of the generator" refers to the torque applied by the generator to the prime mover, in the direction of, or counter to, rotation. The prime
15 mover in most cases may be an engine, but the term engine is used in the course of this specification to also refer to other prime movers which behave similarly to engines, with the characteristics which will be henceforth described.

An example of how torque equilibrium, or lack thereof, can affect speed, is shown in starting an engine-induction generator system, in which the induction generator is supplying electricity to a fixed frequency, fixed voltage, electrical load. When an engine-generator system is started, the speeds of the engine and generator are in fixed relation to each other, but
20 the torques of the individual parts of the system are not. The engine is producing a torque in the direction of rotation, and for equilibrium, the generator would have to be producing an equal torque in the direction counter to rotation. However, since the speed is so low, the generator does not yet generate electricity. In fact, due to the low speeds, the generator absorbs
25 electricity (from another power source) and produces torque in the same direction as rotation. Therefore, the torque produced by the engine is not absorbed by the generator, resulting in system speed acceleration. However, as high enough speeds are reached, the generator begins to generate electricity, and to absorb the torque produced by the engine. There is (in a
30 matched system) at least one equilibrium point, at which the torque output of the engine matches the torque absorbed by the generator, whereupon the system ceases acceleration, and a steady speed is maintained. When changes in
35

system output are required, these are usually made by throttling the engine, or similar methods. Throttling acts to change the torque/speed characteristics of the engine. When throttling is used, the system will often change speed to a different torque equilibrium point, due to the new engine characteristics.

In all examples of engine-generator systems, each of the engine and the generator will have a characteristic that describes how its torque changes with speed. These characteristics will determine the equilibrium speed of the combined engine/generator system.

The generator torque/speed characteristics will depend upon the type of generator it is, its level of excitation, and the load to which it is supplying electricity. Induction generators, when attached to electrical loads having fixed voltage, fixed frequency characteristics, are known to be quite stable, being that within the speed range at which they generate electricity, they have a steep torque requirement relative to their speed requirement. Thus an accidental speed change in a system involving an induction generator will be immediately followed by a large torque change, which normally causes the system to return to equilibrium speed.

Note that in the pathological condition of the engine providing greater torque output than the maximum torque load of the generator, system speed will continue to increase until the internal friction of the engine prevents further speed increase, or until the system fails. This is known as a runaway condition. The maximum torque of an induction generator is limited by the load current. A sudden reduction in load will reduce the maximum torque load of the induction generator, and may cause a runaway condition.

In AC induction machines a method may be applied for the alternation between generator and motor modes. The synchronous speed, the speed of the rotating magnetic field, of the induction machine is determined by the number of poles of the machine and the frequency of the applied AC power. The synchronous speed is given by the formula: $N_s = 120 f / P$ where: N_s is the Synchronous speed in rotations per minute; f is the frequency of the power supply in cycles per second; and P is the number of poles for which the machine is wound.

In induction generators the actual speed of the rotor is faster than the synchronous speed of the rotating field. In induction motors the actual speed of the rotor is lower than the synchronous speed of the rotating field.

In fact, the motor and the generator are essentially the same machine with the main difference being in their actual speed in relation to their synchronous speed; induction machines that are marketed as motors are often placed into service as generators. Although a generator is supplying real
5 electrical power to a load, it is consuming reactive power for excitation purposes. If an induction machine does not have a source of excitation power, then it will not develop a rotating magnetic field, and will not act as a generator.

By controlling the frequency of the input power to the excitation, a
10 controller may increase or decrease the synchronous speed of the machine. For a given rotor RPM, the control may increase or decrease the synchronous speed to be faster or slower than the rotor RPM thereby determining the function of the induction machine as a generator or a motor.

US patent 6054844 granted to Frank describes a system in which the
15 torque applied by a motor/generator to the engine is calculated and applied to force the engine torque to have an ideal relationship to the calculated engine speed. Frank's methods of controlling the engine involve calculations and lookup tables as to how much torque the motor must force the engine to adopt so that the speed/torque relationship of the engine follows an ideal
20 operating line. Another point Frank describes is how the engine is switched off if its speed is too low as to have non-ideal conditions. Furthermore, Frank's system is described only with reference to vehicles, and does not include other applications of engine-generator sets. Whilst the Frank
25 apparatus controls engine power output via the torque/speed curve reflected from the wheels, with corrections for CVT dynamics terms, a need remains for a system which controls engine power output in a fashion which is independent of wheel loads.

SUMMARY OF THE INVENTION

30 The present invention comprises a generator driven by, and connected to, a prime mover, typically a heat engine. The generator is connected to a load and to an electronic control system.

The present invention controls fuel consumption, power output and heat
35 engine operation, by electronic control of the torque/speed characteristics of the generator. This electronic control of torque/speed characteristics is

obtained either by direct control of generator excitation, or by indirect control of the voltage/current or frequency characteristic of the load. Control of the system by electronic control of the generator allows for heat engine operation in a wide open throttle condition, while being able to
5 operate over a large speed range. The quantity of fuel consumed per piston stroke is maximized, and the energy output per piston stroke remains essentially constant. Power output of the engine/generator system is regulated by controlling the number of piston strokes per second. In general, feedback does not directly control engine speed, but instead power
10 output.

In a further embodiment of the present invention, a throttle or fuel metering is used to maintain the charge of fuel and air in the cylinder at a predetermined maximum level. For maximum efficiency, a throttle operated near the wide open condition may be used. Such a throttle may also find use
15 as an emergency shutdown device, in the event of an electrical failure. As used in the method of the present invention, such a throttle does not take part in the primary control of engine operation.

A further embodiment of the present invention is to dynamically control the torque/speed characteristics of the generator in synchronism with the
20 cyclic torque changes of the power output of the heat engine. The generator may act as a motor for part of the heat engine cycle, powering the heat engine during power absorbing strokes of the cycle. This facilitates the use of single cylinder engines, and engines without flywheels.

Objects of the present invention are, therefore, to provide new and improved methods and apparatus for prime mover-generator systems and control
25 over them, having one or more of the following capabilities, features, and/or characteristics:

A technical advantage of the present invention is that it provides new and improved methods and apparatus for prime mover generator systems and
30 control over them. A further technical advantage is to provide a heat engine generator system in which the heat engine can be continuously operated over a wide load range without induction restriction, avoiding the need for engine throttling.

Another technical advantage of the present invention is that higher
35 engine efficiency is obtained by avoiding engine operation in a near closed throttle mode. Further, the heat engine does not have to be turned on and

off in response to demand, but rather the engine runs steadily. This avoids the fumes and pollution caused when a heat engine starts and prevents the loss of rotational energy that occurs from repeated stopping and starting.

A further technical advantage of the present invention is that it provides a heat engine generator system in which control is applied to the generator to electronically regulate the output of the system. Thus, control over the output of the system may be faster and more exact. Further, the load on the heat engine may be electrically manipulated to maintain a close to optimal run of the engine.

A still further technical advantage of the present invention is that it provides a method by which a generator may be operated periodically as a motor. This allows the heat engine operation, during power absorbing strokes, to be improved by a periodic transfer of power from the generator, acting as motor, back to the engine. Thus, the present invention provides a simple method by which an electrical machine may alternate between generator and motor operation without direct control intervention, and without need to synchronize controller operation to heat engine operation.

Other technical advantages of the present invention are set forth in or will be apparent from drawings and the description of the invention that follows, or may be learned from the practice of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete explanation of the present invention and the technical advantages thereof, reference is now made to the following description and the accompanying drawings, wherein like reference numerals represent like parts, in which:

Fig. 1 illustrates an embodiment of the present invention;

Fig. 2A shows one embodiment of the present invention in starting mode or during power absorbing strokes of the engine;

Fig. 2B illustrates one embodiment of the present invention in running operation during power strokes;

Fig. 3 is a graph of engine and generator torques in one embodiment of the present invention;

Fig. 4 is a torque/speed diagram for an internal combustion engine and a DC generator coupled to a set of resistive loads;

Fig. 5 is a torque/speed diagram for an internal combustion engine and an AC induction generator coupled to a power electronic control;

5 Fig. 6 is a torque/speed diagram for an internal combustion engine and a DC generator coupled to a power electronic load accepting current at various threshold voltages;

Fig. 7 is a torque/speed diagram for an internal combustion engine and a DC generator coupled to a power electronic load accepting current at
10 various threshold voltages, with sourcing current;

Fig. 8A is a representation of a boost converter with feedback drawn from the input;

Fig. 8B is a representation of a boost converter load combined with a buck converter power supply;

15 Fig. 9A is an arrangement of the alternator in one embodiment of the method of the present invention; and

Fig. 9B is a torque/speed diagram for an internal combustion engine and an alternator supplying power to a battery.

20 DETAILED DESCRIPTION OF THE INVENTION

Embodiments of the present invention and their technical advantages may be better understood by referring to Figs. 1 through 9, like numerals referring to like and corresponding parts of the various drawings.

25 Fig. 1 shows a schematic overview of the present invention. Prime mover 11 is connected to an electric generator 12 via shaft 18. Generator 12 is connected to power electronic converter 13 via wiring 20. Converter 13 is further connected to electrical load 14 and energy storage unit 16.

30 Figs. 2 show a schematic overview of power flows in the present invention when the heat engine is a single cylinder engine. The bold arrow represents the instantaneous direction of the power flow. Fig. 2A represents the system in starting mode or during power absorbing strokes of the engine 11A, when the generator 12 is powered by the energy storage unit 16 and driven to act as a motor. Fig. 2B represents the system in running operation

during the power strokes. The generator 12 is powering the electrical load 14 and charging the electrical storage unit 16.

Fig. 3 is a graph of the engine and generator torques in one embodiment of the present invention. The engine is a single cylinder diesel engine coupled to an appropriately sized induction generator. The horizontal axis of the graph is time, while the vertical axis of the graph is torque in the direction of rotation. The horizontal axis is divided amongst the four strokes of the engine.

Fig. 4 is a torque/speed diagram for an internal combustion engine and a DC generator coupled to a set of resistive loads. Curve M represents the torque/speed characteristic of this example engine, with the horizontal axis representing rotational velocity, and the vertical axis representing torque in the direction of rotation. Curves G, G', G'', G''', ..., G'''''' represent the torque/speed characteristics of the example DC generator under various load resistance conditions, with the horizontal axis again representing rotational velocity, but with the vertical axis representing torque in the direction counter to rotation.

Fig. 5 is a torque/speed diagram for an internal combustion engine and an AC induction generator coupled to a power electronic control. Curve M represents the torque/speed characteristic of an example engine, with the horizontal axis representing rotational velocity, and the vertical axis representing torque in the direction of rotation. Curves G, G', G'', ..., G'''''' represent the torque/speed characteristics of the example AC generator operating at various drive frequencies and a constant voltage/frequency ratio. The power electronic drive is designed to maintain proper voltage while both sourcing and sinking power.

Fig. 6 is a torque/speed diagram for an internal combustion engine and a DC generator coupled to a power electronic load accepting current at various threshold voltages. Curve M represents the torque/speed characteristic of an example engine, with the horizontal axis representing rotational velocity, and the vertical axis representing torque in the direction of rotation. Curves G, G', G'', G''', ..., G'''''' represent the torque/speed characteristics of the example DC generator under various load conditions, with the vertical axis representing torque in the direction counter to rotation. The load in this case is designed to have little current flow until a programmed threshold voltage, followed by increasing

current flow at an incremental resistance of 2.5 ohms, meaning that for every 10 volts above the threshold voltage, current increases by 4 amps.

Fig. 7 is a torque/speed diagram for an internal combustion engine and a DC generator coupled to a power electronic load accepting current at various threshold voltages, with the additional capability of sourcing current. Curve M represents the torque/speed characteristic of an example engine, with the horizontal axis representing rotational velocity, and the vertical axis representing torque in the direction of rotation. Curves G, G', G'', ..., G'''''' represent the torque/speed characteristics of the example DC generator under various load conditions, with the vertical axis representing torque in the direction counter to rotation. The load in this case is designed to source current to the generator until a programmed threshold voltage, followed by increasing current flow at an incremental resistance of 2.5 ohms, meaning that for every 10 volts above the threshold voltage, current consumption increases by 4 amps. The generator will operate as a motor until it reaches a rotational velocity set by the threshold voltage, at which point it will begin to source power to the load.

Figs. 8 are schematic diagrams of power electronic loads. Fig. 8A is a representation of a boost converter with feedback drawn from the input. Fig. 8B is a representation of a boost converter load combined with buck converter power supply to cause the generator to act as a motor at low voltage levels.

Figs. 9 are schematic diagrams of the use of an automotive alternator in the method of the present invention. Fig. 9A is the arrangement of the alternator in the method of the present invention. Fig. 9B is a torque/speed diagram for an internal combustion engine and an alternator supplying power to a battery. The alternator has adjustable excitation. Curve M represents the torque/speed characteristic of an example engine, with the horizontal axis representing rotational velocity, and the vertical axis representing torque in the direction of rotation. Curves G, G', G'', ..., G'''''' represent the torque/speed characteristics of the example alternator under various excitation conditions, with the vertical axis representing torque in the direction counter to rotation. In this case, the load is simply a battery. Current through the alternator rectifier is essentially zero until the alternator voltage matches battery voltage, at which point current and torque begins to rise rapidly. Alternator voltage may be adjusted by adjusting excitation.

In the method of the present invention, the power output of the heat engine/generator system is controlled by electrical manipulation of the torque/speed characteristics of the generator. The present invention comprises a heat engine, an electric generator, and a power electronic control. Electrical energy storage, in addition to suitable control means for the same, may additionally be used. A load consumes the electrical power produced. To facilitate understanding, the common diesel engine rotating an induction generator system will be used to describe a particular embodiment of the present invention. The present invention may be used with all common internal combustion engines, including Otto cycle engines, two stroke engines, and rotary engines, as well as with other prime movers whose potential energy consumption may be controlled by the RPM of the prime mover. The common feature of diesel engines, Otto cycle engines, two stroke engines, and Wankel rotary engines is that air intake and fuel burned are directly controlled by the rotational velocity of the engine. The greater the number of engine cycles per second, the more fuel burned, and the greater the power output. Other devices, for example piston engines operated by steam pressure, share the common feature that rotational velocity determines potential energy consumed and thus, power output.

The heat engine is directly coupled to the generator, via a mechanical means, such as a shaft, or gearing or other speed changing apparatus. The generator converts mechanical power into electrical power, and driving an output current through a load. The torque/speed relation of the generator is electronically controlled, either by direct control of generator excitation, or by control of load voltage/current or load frequency characteristics. Through control of the torque/speed characteristics of the generator, control of the system's rotational velocity is effected without the use of a throttle. The heat engine is operated at wide open throttle, with power variation being achieved through changes in rotational velocity.

To achieve variation in system power output, the speed of the engine is changed to produce the desired power output at wide open throttle condition. The speed of the generator is the same as, or related to, the speed of the prime mover to which it is connected.

In the method of the present invention, the speed of the system can be indirectly manipulated by altering the relationship between the generator's torque requirements and its speed. The engine/generator equilibrium speed is

changed, and the system moves to this new speed. In general, higher engine speed means more fuel consumption and more power output, thus, control of system power output is achieved through the manipulation of generator torque/speed characteristic.

5 The manipulation of generator torque/speed characteristic can be done, for example, in two ways: a switching or changeable load or by changing the excitation magnitude or frequency of the generator. When using a switching or changeable load, the load can be made to draw more or less current. This will increase or decrease the torque requirements, or "torque load" of the
10 generator.

When changing the excitation magnitude or frequency of the generator, the characteristics of the power supplied to the load is changed. In the case of AC machines, the excitation frequency sets the synchronous speed of the generator. In the case of both AC and DC machines, the excitation
15 current sets the strength of the magnetic field in the generator, and thus, the voltage output at a particular RPM.

An AC induction generator contains stator windings which both provide output as well as excitation. The frequency and voltage of the excitation can be modified to produce a difference in the torque load of the generator.
20 The excitation is provided by quadrature AC, that is alternating current in which the current is not in phase with the voltage. Quadrature AC in the stator windings induces current in the rotor windings, and the current in the rotor windings generates the magnetic field. The induction machine excitation can be controlled through the use of power electronics. They can
25 arbitrarily draw current out of phase with the voltage, and can thereby adjust the quadrature current flowing in an induction machine. The power electronic may comprise an inverter, such as is used to operate induction motors in variable speed applications. The use of the inverter allows for direct control of synchronous speed, and thus, control of the equilibrium
30 point between heat engine torque and generator load. The power electronics can also change the voltage that the system is operating at, which will change the excitation current levels. Power electronics can also control the total current drawn, and in this fashion can also adjust machine torque and power output.

35 Similarly, for the synchronous generator, synchronous speed is frequency controlled. A synchronous generator works in the following manner.

In the synchronous machine, the stator poles are magnetized with a rotating magnetic field. The north stator pole is magnetically attracted to the south rotor pole, and the south stator pole is attracted to the north rotor pole.

In generator action the north and south poles of the rotor are slightly ahead of their stator opposites and pull them along. Unlike induction machines, the synchronous machine's rotating magnetic field is rotating at the same velocity as the rotor, which is known as the synchronous speed. However, there is ability for control over the torque load of the generator, in the angular difference between the equivalent poles of the rotor and stator.

This angular difference is directly related to the torque load of the generator on the prime mover.

Control of AC synchronous machines may thereby be achieved through the control of the frequency and voltage applied to the terminals of the machine. The applied frequency can differ only slightly from the actual rotational velocity of the rotor, or the machine will fall out of synchronism. Slight changes in drive frequency will cause the rotor to speed up or slow down in order to return to synchronism. The rotor poles would then, after that brief moment of change, although being in synchronism with the stator poles, be slightly more ahead of, or slightly closer to, their stator equivalents. In this state the generator would be applying a different torque load on the prime mover. Making controlled changes in drive frequency and/or drive voltage may be used in the method of the present invention to actively control the torque load, and thereby the speed and total power output of the prime mover.

The output of the synchronous generator may also be converted, using suitable apparatus, for example an AC input switching power supply may be used to increase the current drawn by the load, again increasing power output and torque load upon the prime mover.

In the case of the DC generator, generator torque load is nearly linear in output current level. Thus, one may dynamically adjust the torque load by changing load resistance, for example, through the use of a DC-DC converter. Generator torque load is also nearly linear with field excitation, thus, generator torque load may be controlled by adjustment of the field, if a suitable load is being supplied.

An AC synchronous generator with a wound rotor, driving a DC load through suitable rectification means, will operate similarly to a DC generator, as described above, and with similar control capabilities.

As stated above, the speed of the engine/generator system is set by torque equilibrium. If, when the system is in equilibrium at a particular speed with a particular torque equilibrium, the torque/speed characteristic of the generator is changed, then for that particular speed the generator will now have a different torque. The torques of the system will no longer be in equilibrium and the speed of the engine will usually change. When the speed of the engine changes, the speed of the generator changes too. The engine/generator system will speed up or slow down depending upon the net total torque between engine and generator.

In the case of a heat engine coupled to an induction generator supplying a constant voltage load, a slight reduction in the excitation frequency will lower system synchronous speed. As the generator's slip has now increased, its torque load will be greater. This will cause the system to slow down. An increase in synchronous speed will decrease the torque load of the generator, and cause the system to speed up. Note that the power electronic controller may be required to source or sink additional drive power during these speed changes, and that the extent of the speed changes will be limited by the maxima of the torque speed characteristics of the generator. If drive frequency is changed such that the generator is operating well above synchronous speed, then the torque maximum may be passed and torque may be reduced.

In the case of a heat engine coupled to a DC generator, a slight reduction in the excitation current will decrease the voltage output of the generator. Presuming a resistive load, this will reduce the current being driven through the load. The torque requirements of the generator are thereby reduced and the equilibrium speed will be at a higher level. The engine/generator system will speed up. An increase in field excitation will increase the voltage and current, and hence the torque load of the generator and cause the system to slow down. The excitation field is often produced by an electromagnet, allowing the field excitation to be electronically controlled.

The power output changes need not be preceded by a closing or opening of a throttle. The imbalance between the torque output of the engine and the

torque load of the generator, caused by changes in the electrical characteristics of the generator, changes the speed of the engine. It is the change in engine speed that causes the fuel draw of the engine to change.

It should be noted that a change in power requirements does not mean that the power requirement is immediately met by the power output of the generator. In order to reduce the power output of the system, the system speed is reduced. But in order to reduce system speed, the torque load of the generator is increased, in order to cause the RPM change. Power is given by the product of torque and rotational velocity. Thus, the torque has increased, but rotational velocity has not had time to change. To slow the system down in response to a reduction in load, for a moment the power output is increased. Likewise, in response to a required increase in load, for a moment the power output is decreased. Changes are arranged by altering the net torque of the system with the goal of modifying the RPM of the engine, and thereby changing the power output of the system.

The above torque equilibrium may be supplemented and further clarified by consideration of power equilibrium.

In order to maintain and control the speed and power output of the engine while keeping its throttle at the wide open state, the following control procedure may be used:

(One) If the engine is rotating too fast and therefore consuming too much fuel and producing too much power, then more torque is absorbed by the generator and the load, slowing down the engine, or

(Two) if the engine is rotating too slowly, then less torque is absorbed by the generator and the load, causing the engine to speed up.

This control procedure may be understood in terms of the torque balance description presented above. Rotational power is given by the product of torque and rotational velocity. As the engine and generator are locked together in terms of rotational velocity, the only variable is the torque.

If the engine torque is greater than the torque being absorbed by the generator, then the engine power will be greater than the power being absorbed by the generator, and the system will speed up. If the engine torque is less than the torque being absorbed by the generator, then the engine power will be less than the power being absorbed by the generator, and the system will slow down.

A throttle not being intrinsic to the present invention, it nevertheless may play a role in such systems. For example, it may be used for emergency overall control, for shutdown, or for very speedy changes, with the method of the present invention used afterwards to achieve a more
5 efficient engine performance, or a throttle may be used to put limits on the amount of fuel the engine may speed up to, for example, when the control over the current being automatic and subject to error or overload.

EXAMPLES

10 As described above, there are numerous generators which may be considered for the present invention, each with several torque control strategies, and all supplying electrical power to a load which itself may be subject to one of several control strategies. Below are specific examples of the present invention, using a few of the many possible combinations of
15 generator, control technique, and load. The following examples are intended to be purely exemplary, and should not be construed to limit the present invention in any fashion.

Example 1 - Changing a Resistive Load on a Generator

20 For example, the present invention may be used with a DC generator supplying a resistive load. Similar results will be obtained from a synchronous AC generator supplying a resistive load with no frequency regulation, or to an AC induction generator with passive supply of excitation, (e.g. a capacitive excitation supply). The immediate example
25 will not work with an AC machine operating on a fixed frequency load.

An engine produces a mechanical power output. This mechanical power is converted by a generator into electrical power. The electrical power is fed to a resistive load where it is dissipated. Due to external control input, decreased power supply is needed (for example, a thermostat has signaled a
30 state of sufficient heat). To reduce the engine power output, the fuel being consumed by the engine is reduced, which is done by slowing the engine down.

To slow the engine down, the torque load of the generator is increased. This may be accomplished by an increase in the power output of the generator.

The generator torque load may be increased by increasing the output current supplied to the load. This may be accomplished by a decrease in the resistance of the load on the generator. More current flows through the lower resistance, and causes the torque load of the generator to be immediately increased. The torque of the system is no longer in equilibrium, the torque of the engine being lower than the torque load of the generator. The speed of the engine decreases, and with it, the engine torque changes according to its torque speed characteristics. When the required engine power output, determined by the product of engine torque and speed, is reached, the load resistance is increased to reduce the generator torque load and restore engine/generator torque equilibrium. Since there is again equilibrium between torque and torque load, the system stops decelerating. At this point the engine is running at a lower speed and with an appropriate torque to maintain that speed and the generator's decreased power requirement is being met. A slightly different method is to decrease the load resistance, and to let the engine/generator system come to equilibrium with the new load resistance. As the engine/generator system slows down, the generator voltage automatically decreases, thus, decreasing the current flow through the resistive load. As the generator torque comes into equilibrium with the engine torque, the system speed will begin to change.

When an increased power supply is desired, the opposite is done. The torque load of the generator is decreased. The load resistance of a resistive load on the generator is increased. This causes the torque load of the generator and the torque of the engine to cease to be in equilibrium, and in this case the speed will increase. When the required engine power output is reached, an increased torque load is applied, equal to the torque output of the engine. The system ceases to accelerate since there is torque equilibrium.

Again, a single step process is possible in which the resistance of the electrical load is simply increased, and the engine/generator allowed to come to equilibrium with the new load.

With reference to Fig. 4, a graph of torque versus speed for both an internal combustion engine and for a DC generator with various resistive loads is shown. To simplify the example, the effects of armature reaction are ignored. Armature reaction is the factor that reduces the voltage output of a generator as its output current increases. Thus, the actual output of

the generator will be somewhat different from the values calculated herein, in that the torque/speed curves for the generator will curve toward horizontal as torque increases, until a maximum current and torque is attained. However the general nature of the output changes will provide a valid example of the method of the present invention. Generator efficiency is also ignored.

The abscissa of the graph of Fig. 4 represents speed in radians per second, while the ordinate of the graph represents torque in meter newtons. Curve M represents the torque of the engine, with positive ordinate values representing power output of the engine, that is torque in the direction of rotation. Curves G, G', G'', G''', etc. represent the torque of the generator with various resistive loads, with positive ordinate values representing power consumption of the generator, that is torque in the direction opposite that of rotation. Curves G, G', G'', G''', etc. are labeled with the resistances placed on the generator for each curve. A state of equilibrium is achieved when the total torque on the shaft between engine and generator is zero, that is, when engine torque output is equal to generator torque input. This is represented graphically by the intersection of an engine torque/speed curve and a generator-load torque/speed curve.

The example generator produces 2000 V output at 400 radians per second, with a maximum continuous current rating of 50 A, and a maximum rotational velocity of 500 radians per second. The example internal combustion engine has a slightly curved torque characteristic, ranging from 180 meter newtons at its minimum speed of 50 radians per second, to a peak of 200 meter newtons at 200 radians per second, decaying to 175 meter newtons at its maximum rotational velocity of 400 radians per second.

For example, consider operation of the above system with a 25 ohm load. To describe the 25 ohm load line, two points of the line are calculated. The first point is the torque at zero speed. At a rotational velocity of 0 radians per second, the generator voltage will be 0, and thus, the current flowing through the load will be 0. Generator torque will therefore be 0. At a rotational velocity of 400 radians per second, the generator voltage will be 2000 V, and the current flowing through the load will be 80 amperes, an overload condition. The power output of the generator is 2000 V times 80 A, or 160 kW. To provide 160 kW at 400 radians per second, the generator torque must be 400 meter newtons. The intersection of this load line with

the engine torque curve is at 200 radians per second and 200 meter newtons. At a rotational velocity of 200 radians per second, the engine is providing a torque of 200 meter newtons, or a power of 40 kW. The generator is locked to the engine at 200 radians per second, and with this particular resistive load is providing a torque load of 200 meter newtons. Thus, the engine and generator are in torque equilibrium, and system power output is 40 kW.

When there is a change of operation to a 20 ohm load, the 20 ohm load line also passes through zero torque at zero speed. At 400 radians per second, the generator voltage is 2000 V, and the current through the load is 100 amperes, with a power output of 200 kW, and a generator torque of 500 meter newtons. At 200 radians per second, the equilibrium point for a 25 ohm load, the generator voltage is 1000 V, the current through the load is 50 amperes, and the generator torque is 250 meter newtons, considerably more than the torque output of the engine at 200 radians per second. The intersection of the 20 ohm load line and the engine torque curve may be determined graphically to be at about 158 radians per second, with a torque of 198 meter newtons. The generator output voltage is 790 volts, and the current through the load is 39.5 amperes, for a power output of 31.2 kW. By decreasing the load resistance equilibrium operating point is changed and the power output of the engine/generator system is reduced, without the use of a throttle.

At the point that the load resistance is changed to 20 ohm resistance, with the system ~~is~~ at equilibrium with a 25 ohm load, with a power output of 40 kW and a rotational velocity of 200 radians per, at that instant, the generator is still rotating at 200 radians per second, and sourcing 1000 volts. 50 amperes will flow to the load, and at the instant of the change over, 50 kW is being supplied to the load, an increase in power output. However the engine/generator system is not in equilibrium, and will slow down, eventually reaching the desired lower power output level.

The load resistance may also be changed in a continual fashion, to reduce the surge of output power that occurs with a sudden load resistance change. Going to the opposite extreme, the load resistance may be changed beyond that required by the new equilibrium, to be restored to the equilibrium resistance when the appropriate value when the calculated system speed is reached. This will increase both power surges or deficits, and further increase the rate at which system speed changes.

Graphical or mathematical techniques, may be used to determine equilibrium power output of an engine/generator system given a particular resistive load.

5 **Example 2 - Changing the Excitation Frequency**

Another way to change the torque load of a generator involves changing the excitation frequency of the generator, as described above. This changes the synchronous speed, and the difference in initial speed relative to the synchronous speed causes a generator torque change. This causes a changed electrical power output, a changed torque load, and acts to change the engine/generator speed. While these changes are taking place, the load on the generator will see a constantly changing power supply. If this is inappropriate, then excess power supplied will have to be diverted to a secondary load, and a reduced power supply will have to be supplemented from a separate power source. Change in synchronous speed is a technique applicable to AC generators, such as induction or synchronous machines.

In general, to slow down the heat engine, the excitation frequency will be decreased, and to speed up the heat engine, the excitation frequency will be increased. In the case of an AC induction generator operating in its normal operating range, torque changes in an essentially linear fashion about synchronous speed, with zero torque right at synchronous speed, a positive torque load for rotor speeds above synchronous speed, and negative torque loads (motoring operation) below synchronous speed. Real power output will change along with such changes in generator torque, and the electrical load on the generator is compatible with such power output changes, e.g., a resistive load as described above works during generator operation, whereas some sort of battery would be necessary for motoring operations.

It is possible to change the synchronous speed to achieve the desired change in one step. However, large changes in synchronous speed could result in non-desired results. The torque/speed curves have maxima, and the trending in both directions towards equilibria only happens if the torque load is below the generator side maximum. Beyond that point, if the generator torque load is greater than the engine torque, the system may slow down towards equilibrium, but should the generator torque load be lower than the engine torque, then the system will accelerate and continue to do so. Therefore, when the system is to be sped up by a large amount, it may be

necessary to change the generator torque load in stages, to produce a slower and more gradual change.

For example, a slow change may be appropriate if there were no energy storage, a slight lowering in power was desired, and the amount of time
5 needed to reach the new power level was not a factor.

A fast change may be appropriate if there was an energy storage or supply, and the amount of time need to reach to the new power level was a factor.

With reference to Fig. 5, a graph of torque versus speed for both an
10 internal combustion engine and for an AC induction generator connected to an excitation source operating at various frequencies is disclosed. The abscissa of the graph represents speed in radians per second, while the ordinate of the graph represents torque in meter newtons. Curve M represents the torque of the engine, with positive ordinate values representing power
15 output of the engine, that is torque in the direction of rotation. Curves G, G', G'', G''' , etc. represent the torque of the generator with various excitation frequencies, with positive ordinate values representing power consumption of the generator, that is torque in the direction opposite that of rotation. Curves G, G', G'', G''' , etc. are labeled with the excitation
20 placed on the generator for each curve. In this particular instance, the excitation voltage is proportional to the excitation frequency, meaning that excitation remains constant. The power electronic drive/load must source or sink current as appropriate to maintain proper operating voltage. Note should also be made of the fact that on each curve, below the excitation
25 frequency, the generator is operating as a motor. It is also useful to note that the generator will act as a motor, and produce torque, at zero speed.

For example, consider an initial condition of the engine and generator not operating. Glow plugs or other startup heat sources may be used in the engine. The power electronic control begins to synthesize alternating
30 current at 100 radians per second (approximately 16 Hz), at suitable voltage for the generator in question. The power electronic control will source considerable current in order to maintain proper operating voltage. The generator will act as a motor, and cause the engine/generator system to start rotation. The engine will consume fuel and air, and start producing power.
35 The combination of the torque provided by the engine and that provided by the generator will cause the engine/generator system to swiftly accelerate past

synchronous speed. At this point, the generator will begin to convert mechanical power into electrical power, and placing a torque load on the system. At a system speed of about 108 radians per second, the generator torque will balance the engine torque, and the system will cease to
5 accelerate. Power output will be about 21 kW.

The power electronic control synthesizes alternating current at 200 radians per second, again as suitable voltage. The generator is now operating on a new torque/speed curve, and at the current system speed of 100 radians per second will operate as a motor. The combination of engine and
10 generator torques act to accelerate the system to approximately 208 radians per second. At this point, equilibrium will obtain with a power output of about 42 kW. During the initial acceleration phase, the system is actually absorbing power, which must be supplied by energy storage connected to the power electronic converter.

For power output reduction, the drive frequency and synthesis speed is to be reduced. The reduction of drive frequency is limited by the maximum torque range of the generator. If the synchronous speed is reduced so much that generator torque is less than the torque output of the engine, then the system will start to accelerate and enter a runaway condition. A runaway
15 condition occurs when the torque output is greater than the maximum torque load of the generator system, such that the speed will continue to increase until the internal friction of the heat engine prevents further speed increase, or until the system fails.

As mentioned above, small changes in synchronous speed may be used to cause slow changes in power output with only small surplus or deficit power output levels. In situations where such surplus or deficit power is not a
20 problem, extremely rapid changes in power output may be effected. As described above, the example system is simply capable of starting the heat engine.

Specific values of torque, rotational velocity, torque versus slip, and slip are specific to the example engine and generator described above. Different implementations of heat engine connected to induction machine will operate at different torques, slips, and rotational velocities.
30

Another way to change the generator synchronous speed is to vary the
35 number of magnetic poles developed in the generator. One way to do this is by

taking advantage of the pole changing capabilities of motors and generators having high phase counts, such as a 30 phase generator.

Example 3 - Power Electronic Pseudo-Resistive Load

5 A variable resistive load may be used to control the torque/speed characteristics of a generator, thereby obtaining control of engine/generator speed, engine mechanical power output, and thus, engine/generator electrical power output. Such a load need not be an actual resistor, but may be any load with a generally resistive character. Of specific interest are loads
10 which have positive incremental resistance; loads for which current will increase when voltage increases, even if the ratio of current to voltage is not constant as it would be in a true resistor.

As noted above, there is generally an increase in output voltage as the generator speeds up. The value of positive incremental resistance is that as
15 the voltage increases, the current drawn by the load will increase, increasing the torque load of the generator. A generator providing power to a load with positive incremental resistance will be stable to perturbations in prime mover speed, because an increase in prime mover speed will cause an increase in generator torque, acting to slow the system down, while a
20 decrease in prime mover speed will cause a decrease in generator torque, acting to return system speed to the equilibrium value.

As mentioned above, switching power supplies may operate as constant power loads, which have negative incremental resistance, and can cause inherently unstable operation of an engine/generator system. However,
25 switching power supplies may also act as resistive loads, and may be designed so as to act as pure resistors, or to simply have positive incremental resistance over part or all of their operational range. Of particular interest are switching power supplies that draw little or no current until a particular threshold voltage is reached, at which point they steeply increase
30 their current draw as voltage is increased.

Referring to Fig. 4, the intersections of the high resistance load lines with the engine load line get increasingly shallower as power output increases. This means that the natural stability mentioned above will be reduced. Further, the rate at which engine speed changes in response to

commanded change becomes less as power output increases. This situation may be enhanced through the use of pseudo-resistive loads.

With reference to Fig. 6, a power electronic load is designed so as to operate with positive incremental resistance. This load draws little or no current until a programmable threshold voltage, at which point current increases at a rate of 0.4 amp per 1 volt change, or an incremental resistance of 2.5 ohms. The power electronic load is further designed to not draw more than 50 amps, thus, preventing generator overload. Generator voltage is directly related to rotational speed, while generator torque is directly related to current draw, in this example using the same sample generator as example 1. Thus, each electrical load line, selected by selecting controller threshold voltage, may be assigned to a generator torque/speed curve.

With most resistive loads, system rotational speed, and thus, power output, is controlled by the equilibrium between generator torque/speed characteristic and engine torque/speed characteristic. Also, as most loads, the generator torque/speed characteristic is set by the electrical voltage/current characteristic of the load. The improvement is that power electronic load provides for a rapid change of torque versus speed about the desired equilibrium rotational velocity, thus, improving operational stability at the desired power output. Further, the current draw of a power electronic load may be limited to a maximum design to not overload the generator. The incremental resistance of a power electronic load is an aspect of its design, and may be tuned to a particular engine, generator, or load.

A power electronic pseudo resistive load may be used with a DC generator, with a synchronous generator, or with an induction generator, if excitation frequency is not fixed, for example with capacitor excitation.

A power electronic load is quite similar to a power electronic power supply; the essential difference is in the feedback loop. In a power supply, the output is sampled, and errors in the output are corrected through suitable adjustment of the active control elements. In a power electronic load, the input is sampled, and errors in the input are corrected through suitable adjustment of the control elements. Both input side voltage and input current are sampled. The control element is adjusted so as to maintain a desired relationship between input voltage and input current. This may be

done by maintaining a constant ratio between input voltage and input current, thereby synthesizing a resistive load. More complex voltage/current ratios may be designed for, and voltage/current ratio may be adjustable. Power electronic loads may also be programmed to sample the frequency of AC current input and maintain desired frequency characteristics.

With reference to Figs. 8, a block schematic diagram of an adjustable threshold constant incremental resistance power electronic load is depicted. The power electronic circuit itself is called in the art a boost converter. Electrical current flow is from the source, through an inductor, through a switching control element, and back to the source. A high voltage load is also connected to the switching element, through a diode. In operation, the switching element is alternately closed and opened at a rapid rate. When the control element is closed, the source is short circuited through the inductor, storing energy. When the control element is opened, the inductor attempts to maintain current flow, and forces current through the high voltage load, dissipating the energy stored in the inductor.

The current flow from the source is controlled by the duty cycle of the control element. Normally, the output voltage would be sampled, and the input current would be adjusted to control output voltage. In the present usage, the input voltage and current are sampled. The input voltage and current are sampled prior to the control element. A threshold voltage is subtracted from the input voltage using a rectifier. The voltage above threshold is now compared with a scaled voltage that is proportional to the current. Any difference between sensed current and desired current is used to drive an integrator, which adjusts the control element. In the case that current flow is exactly that desired, the input to the integrator will be constant, the integrator output will be constant, and the control element will maintain its desired state.

With a power electronic load, the input is controlled, and the output is varied to maintain the appropriate input. For example, a power electronic load synthesizing a resistor will reduce its current consumption in the event that supply voltage is reduced. Output voltage and current will change as appropriate to the new power level. The output may be, for example, a high voltage traction battery used in a hybrid electric vehicle. The power supplied to this battery would change in a fashion controlled by the input voltage to the power electronic load.

Example 4 - Power Electronic Pseudo-Resistive Load with Energy Storage

With the addition of energy storage needed for smooth supply of electrical power to the final load, additional options are available for a power electronic load. A suitably designed power electronic load may be capable of sourcing as well as absorbing power. In some cases, such capability is an inherent part of the load design, in other cases a load must be designed specifically for power sourcing applications. The present example will function with a brush comutated DC generator, or with a brushless DC motor modified with suitable back diodes so as to be capable of generator operation.

The inverter drive for an induction generator must be capable of supplying power to the generator, operating the generator as a motor. This is necessitated by the fact that induction machines consume reactive power. Reactive power means that current and voltage are not in phase, and that energy is circulating between the generator and the inverter. An inverter must therefore include a small amount of energy storage, and must be capable of sourcing a small amount of energy. With the addition of more extensive energy storage on the DC link, the generator may be caused to act as a motor for an extended period.

In the case of a DC generator with independent excitation, the generator may be caused to act as a motor by reversing the flow of armature current through the machine. With reference to Fig. 7, a power electronic load is designed so as to operate with positive incremental resistance and with current sourcing. This "load" actually supplies 10 amperes of current until a programmable threshold voltage, at which point current consumption increases at a rate of 0.4 amp per 1 volt change, or an incremental resistance of 2.5 ohms. At 25 volts above the threshold voltage current is zero, and as voltage rises current consumption increases. The power electronic load is further designed to never draw more than 50 amps, thus, preventing generator overload. However, in conditions of excessive rotational velocity, the generator is allowed to go into overload in order to prevent an engine over-speed condition. The power electronic load supplies electrical power to a high voltage traction battery. Generator voltage is directly related to rotational speed, while generator torque is directly related to current draw, in this example using the same sample generator as

example 1. Thus, each electrical load line, selected by selecting controller threshold voltage, may be assigned to a generator torque/speed curve.

Below the threshold voltage, current flows through the generator in the opposite direction of the generator produced voltage; electrical power is being supplied to the generator and the generator is acting as a motor. The power electronic load in this case is acting as a power electronic power supply, producing a terminal voltage which is greater than the generator voltage, thus, causing current flow through the generator. For the example generator, a current of 10 amperes corresponds to a force of 50 meter newtons. As the threshold voltage is reached, current supplied to the generator is reduced, and the generator ceases to act as a motor, and begins to supply power to the load. Equilibrium between engine torque and generator torque load is as before; power output is adjusted by changing the position of this equilibrium by changing the threshold voltage.

Note that the transition between motor cranking, to start the engine, and generator operation, in order to generate electricity, is entirely automatic. If the engine is slow to start, then the engine will not produce torque, and the generator system will continue to act as a motor. Further, there is no need to know the exact speed of the engine. Rather, the threshold voltage is controlled based upon the desired power output. If the system power output is less than desired, then the threshold voltage is increased. Similarly, if too much power is being produced, then the threshold voltage is decreased. Power output may thus be controlled over a large power range.

A circuit may be implemented with the above DC active load with energy storage. With reference to Fig. 8A, a DC generator is connected by means of an inductor, a transistor, and a diode to a battery. The control circuitry, transistor drive circuitry, voltage and current detection means, as well as the specifics of the transistor and diode components, are also included. The battery voltage is higher than the generator voltage, and the configuration of inductor, transistor, and diode is known as a boost converter. During operation, the transistor is switched on and off at a rapid rate. When the transistor is on, the generator voltage is applied to the inductor, causing current to flow and energy to be stored in the inductor magnetic field. When the transistor is switched off, the energy stored in the inductor is used to maintain current flow. The voltage across the inductor changes, increasing

to the point that the diode conducts, and energy stored in the inductor is supplied as a charging current to the battery.

With reference to Fig. 8B, the addition of an additional transistor and diode allow for similar operation with the additional capability of supplying power from the battery to the generator. When operating as a load, transistor A is switched as above. With transistor A off, power supply capability is as follows. Transistor B is switched on. As the battery voltage is greater than the generator voltage, current flows through transistor B, the inductor, and then to the generator. This causes the generator to act as a motor. To regulate the current through the generator, transistor B may be switched at a rapid rate; the duty cycle of transistor B controlling the current supplied to the generator. The catch diode and inductor act to provide continuous current flow even as transistor B is switched on and off. When transistor B is switched off, the inductor will maintain current flow, the current flowing through the diode. Transistors A and B are restricted to not being on at the same time. Transistor B, the catch diode, and the inductor form a "buck" converter for supplying power from the battery to the generator. It may be possible to dispense with the inductor entirely, depending solely upon the natural inductance of the motor itself to provide current smoothing action.

Interface of this embodiment of the present invention to an external load is particularly easy. A load is designed so as to consume power at the battery nominal voltage. This may be, for example, the motor of an electric car, operated through a suitable controller. The generator controller monitors the state of charge of the battery, though the simple expedient of measuring actual battery voltage. In response to increasing depth of discharge, or to increasing rate of discharge, the generator controller would command an increase in power electronic load threshold voltage. This would move the engine/generator equilibrium point to higher speeds and power levels. Additional fuel would be consumed, additional power would be delivered to the battery, and the battery would be recharged. As the battery achieves full charge, or as the rate of discharge decreases, the generator controller would command a decrease in power electronic load threshold voltage. This reduces the speed of engine/generator equilibrium, and less power would be delivered to the battery.

Example 5 - Resistive Load with Excitation Control

Generator voltage is directly related to the rotational velocity of the generator rotor. Generator voltage is also directly related to excitation level. At the same rotational velocity, doubling excitation level will roughly double generator output voltage. Doubling excitation level will also double torque for a given output current level. The effects of armature reaction are ignored in this description, since they do not affect the general trends described. If excitation is doubled, with a constant resistive load, then output voltage will be doubled, current flowing through the load will double, and generator torque load and power output will increase by a factor of four. This increase in torque load will cause the engine/generator system to slow down.

Doubling the excitation level will have roughly the same effect as quartering load resistance. A change in excitation level may be understood having the same effect as a change in resistance equal to one over the square of the excitation change.

The method of the present example embodiment is applicable to DC generators with separate excitation. It is also applicable to AC synchronous generators with variable excitation when operating frequency independent loads.

In an exemplary embodiment, a diesel engine provides mechanical power to an AC synchronous generator with external excitation. Electrical power from the generator is used to operate an electrical resistance heater. The diesel engine has a fixed fuel injection setting.

When it is desired to increase the heat being produced by the heaters, the generator excitation is reduced. This causes the engine/generator system to speed up, until equilibrium is achieved at a higher rotational velocity, with higher voltage and current. When it is desired to reduce the heat being produced by the heaters, the generator excitation is reduced.

Example 6 - Battery Load with Alternator

Of particular value for automotive applications is the use of an alternator as the generator. An alternator is essentially a brushless DC generator, comprising a stator with a three phase winding, and a wound rotor producing a suitable magnetic field, and suitable rectifiers on the stator

circuit to provide a DC output. In most alternators, the excitation is provided by means of current supplied to the wound rotor by means of slip rings. Excitation is generally controlled in an automatic fashion in order to maintain a fixed output voltage over a wide load range. The alternator is of particular value because it is already in common use for automotive applications.

With reference to Fig. 9A, an engine and alternator connected for use in the method of the present invention is shown. In this case, the alternator presents the primary load on the engine, rather than a minor secondary load. The three phase stator winding connects by means of the full wave rectifier to the battery. Control is provided by means of excitation change, similar to example embodiment 5 described above. The battery, however, presents an extremely non-linear load. At low rotational velocity, alternator output voltage is lower than battery voltage, and the rectifier is back biased. Output current is thus, essentially zero, and alternator torque load is minimal. As the alternator output voltage becomes comparable to battery voltage, current and torque increase rapidly, limited only by the extremely low resistances of the battery circuit and by armature reaction.

With reference to Fig. 9B, a graph of torque versus speed for both an internal combustion engine and for an alternator supplying a battery type load, operating at various levels of excitation is shown. The abscissa of the graph represents speed in radians per second, while the ordinate of the graph represents torque in meter newtons. Curve M represents the torque of the engine, with positive ordinate values representing power output of the engine, that is torque in the direction of rotation. Curves G, G', G'', G''', etc. represent the torque of the alternator with various excitation levels, with positive ordinate values representing power consumption of the generator, that is torque in the direction opposite that of rotation. The exact location of the threshold points on the torque/speed curves will depend upon the state of charge of the battery, but the general nature of these curves will remain unchanged.

As may be noted from the diagram, engine/alternator power output is increased by a reduction in excitation, and reduced by an increase in excitation. This may be understood in the context of the present invention as follows: at a given equilibrium rotational velocity, an increase in excitation will cause an instantaneous increase in power output. This

increased power output is not matched by engine power output, thus the engine/alternator system must slow down. This slowing stops when a new engine/alternator equilibrium is attained. Similarly, a reduction in excitation causes an instantaneous reduction in electrical power output, leaving the engine with excess power to accelerate the system. As the engine is operating in wide open throttle configuration, engine rotational velocity will determine fuel consumption and power output.

An automotive alternator does not normally act as a motor, as the rectifiers are passive commutation devices. However, with the addition of switching elements and a rotor position sensor, an alternator may be modified to act as a brushless DC motor. a modification allows the alternator to act as the starter for the heat engine.

Example 7 -- Generator in Engine Synchronized Periodic Motor Action

The introduction of energy storage and motoring of the generator permits further benefit to be had from the present invention. In heat engines, inertia (the energy of motion of an object) is an important factor. During the engine power cycle, inertia carries the pistons through the power absorbing strokes. To enhance this mechanical energy reserve, a flywheel is placed on the crankshaft to which the pistons are connected. The engine must be operating rapidly enough for sufficient energy to be stored in the motion of the flywheel to allow for the completion of power absorbing strokes. If the engine is operating too slowly, it will stall.

Traditionally, a small electric motor is used to start the engine. This motor, also known as the starter, is coupled to the engine and is started by closing a circuit to an independent energy source, usually a battery. When started, the starter rotates the engine until sufficient inertia is reached and one piston can carry the rest of the pistons through their power absorbing strokes on its own. Once the desired speed is reached, the starter is mechanically disconnected from the engine.

As mentioned above, numerous generator designs may be operated as motors, given suitable electronic control and a source of electrical power, such as a battery. The generator, temporarily acting as a motor, may replace the starter to initiate engine operation. Once the engine gains sufficient momentum, the generator is reset to its original function and the power is

provided by the engine. This eliminates the need, and with it the cost and the complication, of a separate starter unit.

As described above, several generator/load combinations act as motors at low speed, transitioning to generator operation engine speed passes a particular threshold. In the method of the present invention, this threshold is controlled by various means suitable to the generator and load. Further, several generator/load combinations display rapid changes in torque with rotational velocity, meaning that a small change in rotational velocity will cause a large change in generator torque load. Such a "stiff" generator, if capable of motor operation, will act as the flywheel of the engine. During power absorbing strokes, the engine/generator system will slow down slightly, and the generator will begin to act as a motor, supplying the necessary energy to the pistons. During power strokes, the engine/generator system will speed up slightly, and the generator will output electrical power to the battery.

Similar results may be obtained through the use of a position sensing mechanism mechanically coupled to the engine, which would command the generator/load controller to appropriate torque levels at appropriate times during the engine power cycle. Such added complexity may beneficially improve efficiency.

There are two particular advantages to the present example embodiment. First, energy stored in a flywheel increases as the square of the rotational velocity. As the engine slows down, a point may be reached where insufficient energy is stored in the flywheel to carry the engine through energy absorbing strokes, and the engine will stall. The electrical energy storage does not show such a low speed limit; thus, an engine operated in the method of the present invention will be capable of operation at arbitrarily low speed, and thus, arbitrarily low power output. Second, the use of the generator and battery in place of the flywheel will allow for the use of single cylinder engines, which are simpler, have smaller surface area to volume ratios, and are more efficient.

Example 8 - Another Embodiment of a Generator in Engine Synchronized Periodic Motor Action

A single cylinder diesel engine is coupled to an induction generator. The system is operated by electric control that is supplied with DC power by a battery. The electronic control is able to electronically manipulate the current and frequency of the power input to the induction generator. The control is further able to draw power from the battery and provide suitable AC excitation and power to the generator, or to supply suitable AC excitation to the generator while rectifying real power from the generator and supplying power to the battery.

Initiation of system operation is as follows. The control system operates as an inverter to synthesize alternating current of suitable voltage, frequency, and phase so as to cause the generator to operate as a motor, and accelerate the diesel engine to operational speed. The generator, driven by power provided by the control, from the battery, rotates the engine through the intake and compression strokes. Depending upon system inertia, generator torque, and generator synchronous speed, the system may reach the normal operating range at this point, or may take several power cycles for the system to reach the operating range. The normal operating range is that speed range from a few percent below to a few percent above the generator synchronous speed. At the operating range, during the power stroke, the system will speed up above the generator synchronous speed, causing the generator to produce electricity. Then during the power absorbing strokes, the system will slow down below generator synchronous speed, causing the generator to act as a motor, and provide mechanical power to push the heat engine through the power absorbing strokes. Through control of generator synchronous speed, the average system speed may be controlled, thereby controlling the power output of the system. It may be noted that there is no requirement to detect the actual speed of the engine, nor is there need for a sensor to determine the position of the engine in its power cycle. The engine will naturally vary its speed about the synchronous speed of the generator, and power production may be controlled through control of engine synchronous speed.

The above is a description of a single cylinder diesel engine coupled to an electric generator, and a battery, and operated by an electric control. While this description includes many specifics, these, and other descriptions disclosed above, should not be construed as limiting the scope of the invention in any way. For example, the diesel engine, mentioned in the model above, may be replaced with another heat engine equipped with any number of

cylinders, or an Otto cycle engine, or a four cylinder gasoline engine. The engine may or may not be equipped with a turbocharger or an electric supercharger, depending on the manufacture preference. More than one engine may be used to drive the generator, for example, when two very different load modes may require an additional temporary power input, to supply the high load mode. In fact the invention is directed to a prime mover, which may or may not be an engine at all. For example, a water turbine in a dam could utilize the present invention as its control technique, as could other prime movers. It is only for clarity in reading that the prime mover has been referred to almost throughout this specification as an engine, and more specifically, as a heat engine.

The method of the present invention controls the prime mover "fuel" consumption by the motion of the prime mover. Thus, the present invention is suitable for internal combustion engines, pressure operated reciprocating engines, turbine systems over restricted speed ranges, etc. As an example of a system for which the method of the present invention is unsuitable, one may consider a wind turbine, in which the wind blows weather power is being consumed or not. Similarly, a standard twin shaft gas turbine engine, in which the power output shaft is not directly connected to the compressor or fuel supply.

More than one generator may be coupled to the engine as a result of space requirements, separate operational need or other consideration. The engine may be coupled, in addition to the generator, directly to the load; for example, in a vehicle, the engine may be, in addition, coupled to the wheels. As in the model, any type of generator may be used for the conversion of the mechanical power to electrical power. Any type of generator that is capable of acting as a motor may be used in an embodiment that takes advantage of this capability. The present invention teaches how control could be effected without the need for throttle control. There are however embodiments in which a throttle would be part of the engine generator system, e.g., for shutdown, or as a safety device. Power electronic devices for the control and conversion of the electrical power are not limited to those listed, but may include any power electronic switches, including gas discharge devices, mechanical switches, silicon devices, and vacuum microelectronics devices. The extent of the control might range from the manipulation of the generator's output, through control over the generator's excitation levels, to the additional control over the engine's fuel and air

intake. Operation is not limited to the ideal combination of engine speed, winding power and generator electric load, although the invention facilitates operation at such ideal parameters. Direct feedback of heat engine speed may be used to allow the power electronic control to anticipate power output
5 corrections. In addition, other feedback parameters such as engine and winding heat, oxygen concentration in the exhaust path etc. may be collected, depending on the machine function, to reflect the difference between the given condition and the desired one. The power electronic control system may control system rate of speed change, as well as system speed. The power
10 electronic control system may include predictive capability to anticipate future power requirements, and to select power output levels accordingly. The generator controller used to alter the synchronous speed of the generator according to the methods described may include standard field oriented control techniques, which allow the control of electrical machine torque
15 versus speed relations.

While inherently stable embodiments have been described, in which small changes in system speed cause immediate changes in power consumption which restore the system to the desired equilibrium speed, such is not a necessary requirement. The requirement of equilibrium may be met through the use of
20 unstable equilibrium, for example a DC generator supplying a constant power switching load. In such a case, active changes in load power consumption will be needed to maintain system speed, however the unstable nature of the engine/generator equilibrium may enhance the speed with which power output levels may be changed. There are also embodiments in which a further
25 controlling step will prove necessary, to cause the engine and generator to be in an equilibrium state, so that the engine stops changing speed.

There have been described embodiments in which the focus is on the change of power output of the engine, via generator control. Another application of the present invention is with the use of an induction
30 generator having a very high torque to speed relation around synchronous speed. Through this, the generator fluctuates between generating and motoring modes throughout the engine power production cycle itself. As a result, the engine never slows down dramatically during power absorbing strokes, to speed up again dramatically in power production strokes. In such
35 an embodiment, used perhaps in a electricity generation unit, the generator may, or may not also provide control over the output of engine; indeed a throttle may be used to control engine power output.

Some embodiments may use a more limited and some a more expanded control depending on their specific needs. An energy storage unit, such as a battery, may or may not be used. The benefits from the use of the present invention are especially apparent when the invention is utilized in hybrid electric vehicles, heavy machinery and off grid electricity production.

The need for cleaner, more efficient drive means is well established in these fields. However, the benefits of the present invention are not limited only to these examples. In times when environment issues are in the interest of both the public and the legislator, cleaner and more efficient means to produce electrical power are clearly useful and have a great commercial potential.

While this invention has been described with reference to illustrative embodiments, it is to be understood that this description is not intended to be construed in a limiting sense. Modifications to and combinations of the illustrative embodiments will be apparent to persons skilled in the art upon reference to this description. It is to be further understood, therefore, that changes in the details of the embodiments of the present invention and additional embodiments of the present invention will be apparent to persons of ordinary skill in the art having reference to this description. It is contemplated that such changes and additional embodiments are within the spirit and true scope of the invention as claimed below.

I CLAIMED:

1) A prime mover output control system, comprising

- 5 a) a mechanical load, connected to said prime mover for receiving rotating mechanical power therefrom, said mechanical load comprising a controllably adjustable torque requirement from said rotating mechanical power, and
- 10 b) a control mechanism connected to said mechanical load, comprising control over the controllably adjustable torque requirement to effect a resultant change of speed of said rotating mechanical power, and associated change of magnitude of mechanical power, whereby the prime mover power output may be controlled.

15 2) The system of claim 1 wherein said prime mover being of the type whose speed increases when its output torque is externally decreased, and vice versa, and whose power output generally increases when its speed increases due to externally decreased torque, and vice versa, and wherein the direction of said control over the controllably adjustable torque requirement being a:

- 20 a) decrease of the torque requirement of the mechanical load, to effect an increase of the power output of the prime mover, and
- b) an increase of the torque requirement of the mechanical load, to effect a decrease of the power output of the prime mover.

25 3) The system of claim 2 wherein said control mechanism further comprising an input for receiving signals commanding a power output magnitude requirement.

30 4) The system of claim 3 wherein said control mechanism further comprising look-up tables comprising data related to torque requirement/prime mover power output relationships, or further comprising a calculator for calculating torque requirement/prime mover power output relationships; either of which for determining an ideal torque requirement to apply to said rotating mechanical power for the attainment of the power output magnitude requirement.

35 5) The system of claim 4 wherein said ideal torque requirement comprising the ideal torque requirement for the attainment of the power output magnitude

requirement in a single change of torque/speed relation.

5 6) The system of claim 5 wherein said mechanical load being a generator supplying power to an eventual recipient, and wherein said control mechanism comprising energy storage, for supplying the eventual recipient with its required power, substantially irrespective of prime mover output fluctuations caused by prime mover power output change.

10 7) The system of claim 5 wherein said mechanical load comprising an electrical generator supplying electricity to an eventual recipient, and wherein said control mechanism not comprising substantial electricity storage, whereby the eventual recipient receives power of a somewhat fluctuating nature during periods of power output change.

15 8) The system of claim 4 wherein said ideal torque requirement comprising a series of incremental torque requirements for application to the prime mover for the attainment of the power output magnitude requirement.

20 9) The system of claim 8 wherein said mechanical load comprising an electrical generator supplying electricity to an eventual recipient, and wherein said control mechanism not comprising electricity storage, whereby the eventual recipient receives power of a somewhat fluctuating nature during periods of power output change; and wherein said ideal torque requirements comprising torque requirements that cause a power output change that the eventual recipient will not be substantially adversely affected by.

30 10) The system of claim 2 wherein said mechanical load having dynamically unstable equilibrium with prime mover output, and wherein said control mechanism further for stopping said resultant change of magnitude of said rotating mechanical power, said control mechanism comprising

a) a sensor, or

b) a calculator, or

35 c) a combination of sensor and calculator; for determining the torque output of said prime mover at the attainment of a required power output, and

d) a predetermined response to the attainment of the prime mover of a required power output, of the application of the determined torque

output, to said rotating mechanical power.

11) The system of claim 2 wherein said control mechanism comprising
variable mechanical advantage coupling between said prime mover and said
mechanical load.

12) The system of claim 2 wherein said mechanical load comprising a
variable displacement pump and wherein said control mechanism comprising
a) a displacement adjuster, for varying the torque requirement of the
mechanical load, and
b) no power output controlling throttle.

13) The system of claim 2 wherein said mechanical load being a generator
supplying power to an electrical load, and wherein said control mechanism
comprising electronic components for the adjustment of the current drawn
from the generator, to effect control over the torque requirement of the
generator.

14) The system of claim 13 wherein said electronic components comprising
a power electronic converter having an input connected to said generator
and an output connected to the electrical load, said power electronic
converter for controlling the current draw of its own input, to effect
control over current draw from the generator, and thereby the torque
requirement of the generator.

15) The system of claim 14 wherein said generator comprising a direct
current generator and wherein said power electronic converter having
control over its own input voltage versus current characteristics to
control the current draw from the generator, and thereby the torque
requirement of the generator.

16) The system of claim 14 wherein said generator being an alternating
current synchronous permanent magnet machine and wherein said power
electronic converter having control over its own input voltage versus
current characteristics to control the current draw from the generator,
and thereby the torque requirement of the generator.

17) The system of claim 14 wherein said generator being an alternating current synchronous permanent magnet machine and wherein said power electronic converter having control over the frequency of its input to control the current draw from the generator, and thereby the torque requirement of the generator.

18) The system of claim 14 wherein said generator being an alternating current synchronous externally excited machine having fixed excitation, and wherein said power electronic converter having control over its input voltage versus current characteristics to control the current draw from the generator, and thereby the torque requirement of the generator.

19) The system of claim 14 wherein said generator being an alternating current synchronous externally excited machine having fixed excitation, and wherein said power electronic converter having control over the frequency of its input to control the current draw from the generator, and thereby the torque requirement of the generator.

20) The system of claim 14 wherein said generator being an alternating current induction machine and wherein said power electronic converter having control over the frequency of its input to control the current draw from the generator, and thereby the torque requirement of the generator.

21) The system of claim 14 wherein said power electronic converter having positive incremental resistance over part of all of its operating range.

22) The system of claim 21 wherein said power electronic converter having

a) a threshold voltage below which little or no current is drawn from said generator, and above which a steeply increasing current is drawn from said generator, and

b) a threshold voltage adjuster for controlling the current draw of the generator output.

23) The system of claim 22 wherein said control mechanism further having an input for receiving signals to change the power output of the system, said input sampled for said threshold voltage adjuster for adjusting the

threshold voltage based upon said input, whereby said torque requirement and hence the speed and power output of the system may be changed in response to a requirement.

5 24) The system of claim 23 wherein the direction of the control over the controllably adjustable torque requirement of a decrease of the torque requirement of the mechanical load, being an increase of said threshold voltage, and wherein the direction of the control over the controllably adjustable torque requirement of an increase of the torque requirement of the mechanical load, being a decrease of said threshold voltage.

10 25) The system of claim 14 wherein said power electronic converter being a boost converter, a switching element whereof having control over the current/voltage relationship of the generator electrical output, whereby the current of the generator output and the torque requirement of the generator being controllable.

15 26) The system of claim 2 wherein said mechanical load being a generator supplying power to an electrical load and wherein said control mechanism comprising variable resistance connected to the output of the generator, for the control over the current draw from the generator, whereby the torque requirement of the generator being controlled.

20 27) The system of claim 26 wherein said generator being a direct current machine.

25 28) The system of claim 26 wherein said generator being an alternating current machine.

30 29) The system of claim 26 wherein said variable resistance comprising one or more variable resistors.

35 30) The system of claim 26 wherein said variable resistance comprising a plurality of fixed resistance resistors, and wherein said control mechanism comprising switches for switching different resistors in and out of circuit for the creation of desired resistance.

31) The system of claim 30 wherein said variable resistors comprising variable resistance heaters.

32) The system of claim 2 wherein said mechanical load comprising an electrical generator, supplying power to an electrical load, and having controllably adjustable excitation, and wherein said control mechanism comprising control over the generator excitation and thereby control over the torque requirement of the generator.

33) The system of claim 32 wherein said control mechanism comprising control over the synchronous speed versus torque characteristics of the generator

34) The system of claim 33 wherein said generator being a direct current independent wound commutated machine.

35) The system of claim 33 wherein said generator being a direct current independent wound brushless machine.

36) The system of claim 33 wherein said generator being a direct current permanent magnet brushless machine.

37) The system of claim 33 wherein said generator being an alternating current synchronous machine.

38) The system of claim 33 wherein said generator being an alternating current induction machine, and wherein said control mechanism comprising a quadrature current controller for varying the supply of quadrature current to the induction machine.

39) The system of claim 1 further comprising energy storage and wherein said mechanical load comprising:

- a) a generator, and
- b) at least one power electronic converter, and
- c) an electrical load, and
- d) energy storage

wherein said at least one power electronic converter having an input from said generator and being configured to control the electrical

current of said input; thereby controlling the torque requirement of the mechanical load; and wherein said at least one converter having an output to said energy storage for providing it with energy.

5 40) The system of claim 39 further comprising a power electronic converter having an input connected to said energy storage and an output connected to said electrical load, for controllably supplying power to said load.

10 41) The system of claim 40, wherein said energy storage being a battery.

15 42) The system of claim 41, wherein said generator being a direct current or rectified alternating current generator, and wherein said battery having a higher voltage than the output of the generator, and wherein said at least one power electronic converters comprising a boost converter located between the generator and the battery.

20 43) The system of claim 41, wherein said generator being a direct current or rectified alternating current generator, and wherein said battery having a lower voltage than the output of the generator, and wherein said at least one power electronic converters comprising a buck converter located between the generator and the battery.

25 44) The system of claim 39 further including a sensor for determining the position of said prime mover with respect to its power output cycle, said sensor having an output sampled by said at least one power electronic converter, said at least one power electronic converter being configured to command a supply of electrical power from said energy storage to said generator to cause the generator to transition to motor action, during the cyclic periods in which the prime mover is engaged in substantially power absorbing strokes.

30 45) The system of claim 44 wherein said sensor being a rotary angle transducer.

35 46) The system of claim 44 wherein said sensor being a piston position sensor.

47) The system of claim 39, wherein said generator being a brush commutated direct current generator or a brushless direct current motor modified with suitable backdiodes so as to be capable of generator operation and wherein said at least one power electronic converters comprising

5 a) the capability to source power from said energy storage, and

b) current versus voltage input characteristics that cause the automatic transition of generator to motor action and vice versa, around voltages related to converter input voltage,

10 whereby the generator automatically transitions to motor action during reduced voltage periods that occur when the prime mover is engaged in substantially non power-producing periods.

48) The system of claim 47, wherein the power electronic power sourcing load is a combination boost and buck converter located between the generator and energy storage.

15

49) The system of claim 39, wherein said at least one power electronic converter comprising the current versus voltage characteristics which cause the dynamic reduction of generator current during periods of reduced generator voltage, whereby the generator and converter combination act as an electronic flywheel to the prime mover.

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50) The system of claim 39 wherein said at least one power electronic converters comprising a receptor for receiving signals to start said system, and being configured to respond to such signals with the synthesis of suitable current and voltage characteristics for the removal of power from the energy storage to the generator, whereby causing said generator to act as a starting motor to the prime mover.

25

51) The system of claim 50 wherein said generator being a brush commutated direct current generator.

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52) The system of claim 50 wherein said generator being a brushless direct current motors modified with suitable backdiodes so as to be capable of generator operation.

35

53) The system of claim 50 wherein said generator being a rectified alternating current generator and wherein said power electronic converter being a variable frequency power electronic converter.

5 54) The system of claim 1 wherein said mechanical load comprising:
a) a generator, supplying electricity to an electrical load, and
b) energy storage, connected to the output of said generator and the
input of the electrical load via suitable conversion means, and
10 c) generator excitation control, being configured to control the
synchronous speed versus torque characteristics of the generator;
thereby controlling the torque requirement of the mechanical load and
controlling the prime mover speed and power output.

15 55) The system of claim 54 wherein said generator being an alternating
current generator and capable of acting as a motor, and wherein said
generator excitation control comprising
a) adjustable frequency generator excitation current, and
b) power electronic converters, located between said generator and said
20 energy storage for the sourcing and sinking of power for the
accommodation of excitation frequency adjustment.

25 56) The system of claim 55 wherein said generator excitation control
further comprising
a) an input for receiving signals to start said system,
b) programmed response to said signals comprising:
One) increase of excitation frequency from zero, and
Two) supply of suitably synthesized current by said power
30 electronic converters from said energy storage;
whereby said generator excitation control may start said prime
mover.

35 57) The system of claim 54 wherein said generator being an induction
motor capable of acting as a generator, and wherein said generator
excitation control comprising an adjustable frequency inverter providing
adjustable quadrature excitation current to the generator.

58) The system of claim 57 wherein said generator excitation control
comprising:

- a) means to source current from said energy storage to power said generator as a motor, and
- b) permitting the natural generator to motor transition during cyclic power output changes of the prime mover,
- 5 whereby the generator acts as a motor during periods of substantially reduced prime mover torque output.

59) The system of claim 58 wherein said generator replaces a flywheel of the prime mover.

10 60) The system of claim 58 wherein said generator excitation control further comprising

- a) an input for receiving signals to start said system,
- b) inverter frequency increase as a response to said signals, and
- 15 c) electronic converters connected between said generator and said energy storage, for supplying operating power to said generator, whereby said system may be started.

20 61) The system of claim 57 wherein said generator excitation control further comprising

- a) an input for receiving signals to start said system,
- b) means to increase inverter frequency in response to said signals, and
- c) power electronic converters connected between said generator and said energy storage, for supplying operating power to said generator;
- 25 whereby said prime mover may be started.

30 62) The system of claim 1 further comprising energy storage and wherein said mechanical load comprising:

- a) an alternating current generator, and
- b) at least one power electronic converter, and
- c) an electrical load, and

35 wherein said at least one power electronic converter having an input from said generator and being configured to control the frequency of said input; thereby controlling the torque requirement of the mechanical load; and wherein said at least one converter having an output to said energy storage for providing it with power.

63) The system of claim 62 further comprising a power electronic converter having an input connected to said energy storage and an output connected to said electrical load for supplying power to the electrical load at substantially the electrical requirements of the electrical load.

64) The system of claim 63, wherein said energy storage being a battery.

65) The system of claim 64 wherein said at least one converters comprising an inverter followed by a boost converter.

66) The system of claim 62 further including a sensor for determining the position of said prime mover with respect to its power output cycle, said sensor having an output, and wherein said at least one power electronic converters comprising

- a) power sourcing ability, and
- b) an input for sampling the output of said sensor, and
- c) programmed response to a sensor output of low or zero prime mover power output, with a frequency decrease that causes the generator to transition to motor action.

67) The system of claim 66 wherein said sensor is a rotary angle transducer.

68) The system of claim 67 wherein said sensor is a piston position sensor.

69) The system of claim 62, wherein said generator being a brush commutated direct current generator or a brushless direct current motor modified with suitable backdiodes so as to be capable of generator operation and wherein said at least one power electronic converters comprising

- a) the ability to source power from said energy storage, and
- b) input frequency characteristics that cause the automatic transition of generator to motor action and vice versa, around the frequency of the converter input,

whereby the generator automatically or naturally transitions to motor action during reduced frequency periods that occur when the prime

mover is engaged in substantially non power-producing periods.

70) The system of claim 69 wherein said generator is an induction generator.

71) The system of claim 62, wherein said at least one power electronic converter comprising the frequency characteristics which cause the dynamic reduction of generator current during periods of reduced generator frequency, whereby the generator and converter combination act as an electronic flywheel to the prime mover.

72) The system of claim 62 wherein said generator is capable of acting as a motor, and wherein said at least one power electronic converters comprising

- a) an input from said energy storage, and
- b) an output to said generator, and
- c) control over the frequency of electrical current from said energy storage to said generator to enable the powering of said generator as a motor and,
- d) a receptor for receiving a signal during a time-period when said generator is not operational, to power said generator as a motor, whereby said generator may be powered as a starting motor to the prime mover.

73) The system of claim 69 wherein said prime mover is a heat engine comprising a startup heat source, and wherein said at least one power electronic converters comprising

- a) power sourcing ability, and
- b) a receptor for receiving a signal to start said system, and
- c) programmed response to said signal with the synthesis of suitable electrical frequency for causing the generator to act as a motor from zero speed to move said prime mover, whereby said generator may be powered as a starting motor to the prime mover.

74) The system of claim 1 further comprising energy storage and wherein said mechanical load comprising a generator, supplying power to an electrical load, and wherein said control mechanism comprising an

adjustable resistance control, having an input from said generator and being configured to control the electrical current of the input; thereby controlling the torque requirement of the mechanical load; and wherein said control mechanism having an output to said energy storage for providing it with energy.

75) The system of claim 74 further comprising a power electronic converter, having an input connected to said energy storage, and an output connected to said electrical load and having control over the conversion of power from the energy storage to the electrical load to substantially the electrical requirements of the electrical load.

76) The system of claim 75, wherein said energy storage being a battery.

77) The system of claim 75 further comprising;

- a) a sensor for sensing the position of the prime mover with regard to prime mover power producing cycle, and for outputting signals representant thereof, and wherein said resistive converter comprising:
- b) a sampler for sampling the output of said sensor, and
- c) a dynamic resistance increase during prime mover substantially non-power producing cyclic portions, whereby the torque requirement of the mechanical load is reduced when the prime mover is producing less torque.

78) An apparatus for the conversion and regulation of power, comprising:

- a) a prime mover for the production of variable rotary mechanical power, and
- b) a power converter, connected to said prime mover, said power converter for applying a torque to a transmission between said prime mover and itself, and for regulating that torque application, said power converter further having an input for receiving signals commanding variations in said torque application, and wherein said prime mover having a speed substantially affected by the torque application of the power converter to the transmission, and
- c) a power recipient, connected to said power converter, and

d) a well-defined relationship between the torque application of the power converter and the speed of the prime mover, whereby allowing for the regulation of the speed, and thereby of the power output, of the prime mover, by the regulation of the torque application of the power converter.

79) The apparatus of claim 78 wherein said power converter comprising a generator for converting said variable rotary mechanical power to variable electrical power, and a power electronic converter, having control over its own input current, and whereby regulation over the torque application of the generator to the transmission.

80) The apparatus of claim 79 wherein said power recipient comprising an energy storage medium and an electrical load.

81) The apparatus of claim 80 further comprising a signal generator for generating signals regarding the state of charge of said energy storage medium; said signals for receipt by said power electronic converter as commanding changes of the torque application to the transmission.

82) The apparatus of claim 81 wherein said power electronic converter is configured to command a power output decrease by causing a prime mover deceleration, by increasing its own input current from the generator; to command a power output increase by causing a prime mover acceleration, by decreasing its own input current from the generator; and to command a sustained power output by maintaining its own input current.

83) The apparatus of claim 82 wherein said generator being configured to also act as a motor, and having access to an electrical power source, which may comprise said energy storage medium; and wherein said power converter also for achieving a power output increase by causing prime mover acceleration by sourcing current from said electrical power source and supplying said sourced current to the generator, whereby causing the generator to apply a torque to the transmission in the direction of rotation and aiding prime mover acceleration.

84) The apparatus of claim 83 further for starting said prime mover.

85) The apparatus of claim 83 wherein said generator having a relationship with said power electronic converter, wherein a small generator output voltage increase being related to a subsequent large increase in power electronic converter input current, whereby causing prime mover deceleration, and a small generator output voltage decrease being related to a subsequent large decrease in power electronic converter input current or even a supply of current to said generator from said energy storage medium, whereby causing prime mover acceleration, whereby stabilizing the prime mover and generator.

86) The apparatus of claim 85, wherein said prime mover being of the type that does not contain a flywheel, wherein generator output voltage reductions, caused by the prime mover's involvement in non-power producing portions of its power production cycle, cause subsequent large decreases in power electronic converter input current or even a supply of current to said generator from said energy storage medium, whereby acting as an electronic flywheel.

87) The apparatus of claim 86 wherein said prime mover being a single cylinder diesel engine and said generator being an induction machine configured to act as both a generator and a motor.

88) The apparatus of claim 83 further comprising a sensor for determining when the prime mover is in a substantially non-power producing portion of its power producing cycle, and for commanding a signal to said power electronic converter to dynamically decrease its input current or to even supply current to said generator from said energy storage medium during such involvement, whereby causing the generator to act as an electronic flywheel.

89) The apparatus of claim 83 wherein said generator having a relationship with said power electronic converter, wherein a small generator output frequency increase being related to a subsequent large increase in power electronic converter input current, whereby causing prime mover deceleration, and a small generator output frequency decrease being related to a subsequent large decrease in power electronic converter input current or even a supply of current to said generator from said energy storage medium, whereby causing prime mover acceleration, whereby

stabilizing the prime mover and generator.

5 90) The apparatus of claim 89, wherein said prime mover being of the type that does not contain a flywheel, wherein generator output frequency reductions, caused by the prime mover's involvement in non-power producing portions of its power production cycle, cause subsequent large decreases in power electronic converter input current or even a supply of current to said generator from said energy storage medium, whereby acting as an electronic flywheel.

10 91) The apparatus of claim 90 wherein said prime mover being a single cylinder diesel engine and said generator being an induction machine configured to act as both a generator and a motor.

15 92) The apparatus of claim 83 wherein said generator being a synchronous machine configured to act as both a generator and a motor.

20 93) The apparatus of claim 83 wherein said generator being an automotive alternator.

25 94) The apparatus of claim 78 wherein said power converter comprising a generator having variable excitation; the regulation of said excitation providing regulation of the torque application of the generator to the transmission with the prime mover.

30 95) The apparatus of claim 94 wherein the speed of the prime mover being substantially affected by the torque application of the generator to the transmission in the following manner: a generator excitation increase causing a prime mover deceleration and a generator excitation decrease causing a prime mover acceleration.

35 96) The apparatus of claim 95 wherein said power recipient comprising an energy storage medium and an electrical load.

97) The apparatus of claim 96 further comprising a signal generator for generating signals regarding the state of charge of said energy storage medium; said signals for being received by said power electronic converter

as commanding changes of the torque application to the transmission.

98) The apparatus of claim 97 wherein said generator being configured to also act as a motor, and having access to an electrical power source which may comprise said energy storage medium, and wherein said power converter also for achieving a power output increase by causing prime mover acceleration by reducing the excitation of the generator to below the synchronous speed and sourcing current from said electrical power source, to the generator, whereby causing the generator to apply a torque to the transmission in the direction of rotation, and aiding prime mover acceleration.

99) The apparatus of claim 98 further for starting the prime mover.

100) The apparatus of claim 98 wherein said generator having a relationship with said energy storage medium allowing for torque application reductions to the transmission or even generator-to-motor transitioning around the synchronous speed, during periods of reduced speeds.

101) The apparatus of claim 100 wherein said periods of reduced speeds being related to power output reductions of the prime mover being involved in reduced-power producing portions of its power output cycle.

102) The apparatus of claim 101 wherein said prime mover being a single cylinder engine and said generator being an induction machine configured to act as both a generator and a motor.

103) The apparatus of claim 98 wherein said generator being a synchronous generator configured to also act as a motor.

104) The apparatus of claim 98 wherein said generator being an automotive alternator.

105) A method for controlling the output of a prime mover, comprising adjusting a torque load on said prime mover in the following fashion:

- a) during periods of operation wherein the power output of the prime mover is to be reduced, causing the torque load on the prime mover to be greater than the torque output of said prime mover,
- b) during periods of operation wherein the power output of the prime mover is to be increased, causing the torque load on the prime mover to be less than the torque output of the prime mover.

106) The method of claim 105 wherein said method further comprising the step of

- c) during periods of operation wherein the power output of said prime mover is equal to the desired power output, maintaining the torque load on the prime mover in equilibrium with the torque output of said prime mover.

107) The method of claim 105 further comprising the step of

- d) determining the substantially exact torque load at which a dynamically unstable prime mover will maintain a required power output, and
- e) stopping the dynamically unstable prime mover from changing speed by applying the substantially exact torque load to the prime mover upon the substantial achievement by the prime mover of the speed needed for the required power output.

108) The method of claim 105 further comprising the step of

- f) receiving signals signalling the amount by which a torque load on said prime mover is to be adjusted, and wherein said steps (a) and (b) comprising adjusting the torque load according to said signals.

109) The method of claim 105 further comprising the step of

- g) receiving signals signalling the periods in which prime mover power output is to be reduced and signals signalling the periods in which prime mover power output is to be increased.

110) The method of claim 105 wherein step (a) of causing the torque load on the prime mover to be greater than the torque output of said prime mover is accomplished by applying a predetermined torque load increment as many times as necessary until the torque load being greater than the torque output of the prime mover; and wherein step (b) of causing the torque load

on the prime mover to be less than the torque output of said prime mover is accomplished by applying a predetermined torque load decrease as many times as necessary until the torque load being less than the torque output of the prime mover.

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- 111) The method of claim 105 further comprising
- h) receiving signals regarding a required prime mover power output, and
 - i) sampling the difference between prime mover power output and a required prime mover power output, and
 - 10 j) determining a torque load to apply to said prime mover which would effect the required prime mover power output, and
 - k) applying the determined torque load in steps (i), (ii) and (iii).

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- 112) The method of claim 111 wherein said step (i) comprising applying the determined torque load in a single application in steps (i), (ii) and (iii).

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- 113) The method of claim 111 wherein step (i) comprising applying the determined torque load in a number of small stages of changed torque load, in steps (i), (ii) and (iii).

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- 114) The method of claim 111 further comprising the step of
- l) buffering the power supply to an eventual recipient of said prime mover power output during periods of power output change, so that it is not substantially adversely affected by power fluctuations during periods of power output change.

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- 115) The method of claim 111 further comprising the step of
- m) sourcing and sinking and converting power between the prime mover and an eventual recipient of the power output of said prime mover to provide the eventual recipient with power according to the required characteristics of the eventual recipient.

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- 116) The method of claim 111 further not comprising the step of
- n) substantially buffering the power supply to an eventual recipient of said prime mover power output during periods of power output change, whereby the eventual recipient may receive power of a somewhat fluctuating nature during periods of power output change.

117) The method of claim **105** wherein said steps of increasing and decreasing the torque of the mechanical load are done by varying a transmission between the prime mover and the mechanical load.

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118) The method of claim **105** wherein said steps (i) and (ii) of causing the torque load to be greater than and smaller than the torque output of the prime mover are accomplished by altering the mechanical coupling of a mechanical load being supplied with mechanical power by said prime mover, in a required direction and by a required amount.

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119) The method of claim **118** wherein said mechanically coupled load being a variable displacement pump and wherein said altering of the mechanical coupling comprising varying the displacement of the pump.

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120) The method of claim **105** wherein said steps of causing the torque load to be greater than, and less than the torque output of said prime mover, result from varying the torque versus speed characteristics of a load.

121) The method of claim **120** wherein the method of varying a torque versus speed characteristics of a load comprising varying the resistance of an electrical load receiving power from said generator.

20

122) The method of claim **121** wherein step (a) comprising increasing the resistance of the electrical load, and wherein step (b) comprising decreasing the resistance of the electrical load.

25

123) The method of claim **122** further comprising supplying an eventual electrical recipient of the output of the prime mover, with power from an auxiliary source, and sinking power thereto, during periods of power fluctuations due to prime mover speed.

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124) The method of claim **123** further comprising the step of supplying power to the auxiliary source during prime mover operation.

35

125) The method of claim **122** further comprising the steps of

- o) sensing or determining when the prime mover is engaged in a section of its power output cycle in which it is substantially not producing power, and,
- p) dynamically increasing the resistance when the prime mover is so engaged, whereby dynamically reducing the torque load on the prime mover.

126) The method of claim **125** wherein said step (xv) comprising transducing the rotary angle of the prime mover

127) The method of claim **125** wherein said step (xv) of sensing comprising sensing piston position of the prime mover.

128) The method of claim **120** wherein the torque versus speed characteristic being varied by the step of

- q) varying the current versus voltage characteristics of the input to an electrical load that is receiving power from a generator that is providing the torque load on the prime mover.

129) The method of claim **128** wherein said varying the current versus voltage characteristics of the input to an electrical load, comprising

- r) not allowing much or any current to flow to the electrical load below a generator voltage threshold, and
- s) at voltages above the generator voltage threshold, allowing a steeply increasing current/voltage ratio to flow to the electrical load, and,
- t) adjusting the height of the generator voltage threshold to increase and to decrease the electrical current allowed to flow to the electrical load, in the attainment of steps (i) and (ii).

130) The method of claim **129** wherein said step (xix) further comprising the step of

- u) steeply decreasing the current flow to the electrical load substantially immediately following any drop in generator voltage, whereby stabilizing the generator, and acting as an electronic flywheel.

131) The method of claim **129** further comprising the step of starting the prime-mover and generator, where the generator is of the type that can operate as a motor, comprising the steps of:

- v) receiving a command to begin outputting power, and,
- w) synthesizing electricity of suitable voltage and current characteristics from an auxiliary energy supply so as to cause the generator to start rotating, and to rotate the prime mover.

132) The method of claim **129** wherein further comprising the steps of

- x) sourcing power from an auxiliary power supply, and
- y) providing current versus voltage characteristics that cause the automatic transition of generator to motor action when the voltage of the power produced by the generator is reduced due to the prime mover having being engaged in a portion of its power producing cycle in which it produces substantially no power.

133) The method of claim **132** further comprising the step of starting the prime-mover and generator, where the generator is of the type that can operate as a motor, comprising the steps of:

- z) sampling an input commanding system startup, and, upon receipt of a command to start system,
- aa) synthesizing electricity of suitable voltage and current characteristics from an auxiliary energy supply so as to cause the generator to start rotating, and to rotate the prime mover.

134) The method of claim **133** further comprising the step of

- bb) employing a combination boost and buck converter to provide electrical conversion in steps (xvii), (xxiv), (xxv), and (xxvii).

135) The method of claim **120** wherein the torque versus speed characteristic of a load being varied by the step of

- cc) varying the frequency of the input to an electrical load that is receiving power from a generator that is providing the torque load on the prime mover.

136) The method of claim **135** wherein said step of varying the frequency comprising

- dd) not allowing much or any current to flow to the load below a generator frequency threshold, and
- ee) above the generator frequency threshold, increasing the current flow to the load steeply with generator frequency increase, and
- 5 ff) adjusting the level of the generator frequency threshold to increase and to decrease the electrical current flow to the load, to cause the torque load to be increased and decreased, in steps (i) and (ii).

10 137) The method of claim **136** further comprising the step of:

- gg) decreasing the current flow to the load steeply with slight generator frequency decrease, below the generator frequency threshold, whereby acting as an electronic flywheel to the prime mover.

15 138) The method of claim **135** further comprising the step of starting the prime-mover and generator, where the generator is of the type that can operate as a motor, comprising the steps of:

- hh) sampling an input commanding system startup, and, upon receipt of a command to start system,
- 20 ii) synthesizing electricity of suitable electrical characteristics from an auxiliary energy supply so as to cause the generator to start rotating, and to rotate the prime mover.

139) The method of claim **135** wherein further comprising the step of

- 25 jj) sourcing power from an auxiliary power supply, and
- kk) providing frequency characteristics that cause the automatic transition of generator to motor action when the voltage of the power produced by the generator is reduced due to the prime mover having being engaged in a portion of its power producing cycle in which it
- 30 produces substantially no power.

140) The method of claim **139** further comprising the step of starting the prime-mover and generator, where the generator is of the type that can operate as a motor, comprising the steps of:

- 35 ll) sampling an input commanding system startup, and, upon receipt of a command to start system,

mm) synthesizing electricity of suitable voltage and current characteristics from an auxiliary energy supply so as to cause the generator to start rotating, and to rotate the prime mover.

5 141) The method of claim 140 further comprising the step of
nn) employing a combination boost and buck converter to provide electrical conversion in steps (xvii), (xxiv) and (xxv) and (xxvii).

10 142) The method of claim 120 wherein said step of varying the torque versus speed characteristic of a load, comprising adjusting the excitation of a generator that is powered by said prime mover, to attain steps (i) and (ii).

15 143) The method of claim 142, wherein said method further comprising
oo) receiving signals commanding a required prime mover power output,
and
pp) determining a required level of generator excitation for
executing the torque load which would cause the prime mover to move to
the required power output, and
20 wherein said step of adjusting the excitation of a generator
comprising
qq) applying the determined level of generator excitation.

25 144) The method of claim 142 wherein said method further comprising
rr) receiving signals commanding an increase in prime mover output,
and
ss) reducing the generator excitation, to cause an increase in prime
mover output, and
30 tt) receiving signals commanding a decrease in prime mover output,
and
uu) increasing the generator excitation to cause a decrease in prime
mover output.

35 145) The method of claim 144 wherein said step (xlv) comprising
vv) reducing the generator excitation to below the synchronous speed
of the generator, where the generator is one that is capable of acting
as a motor,
and wherein said method further comprising the step of

ww) sourcing power from an auxiliary power supply, whereby causing the generator to act as a motor.

146) The method of claim 145 further comprising employing the generator as a starter motor for said prime mover.

147) The method of claim 145 further comprising the step of charging the auxiliary power supply during operation.

148) The method of claim 146 further comprising the step of diverting excess produced during prime mover power output decreasing periods, to said auxiliary power supply.

149) The method of claim 144 wherein said generator being an induction machine, and said steps (xlv) and (xlvii) involve respectively reducing and increasing the quadrature current supplied to the induction machine.

150) The method of claim 149 wherein said step (xlv) comprising
xx) reducing the quadrature current supplied to the induction machine, to cause the operating speed to be below the synchronous speed of the prime mover-generator combination, where the generator being configured to be capable of acting as a motor, and wherein said method further comprising the step of
yy) sourcing power from an auxiliary power supply, whereby causing the generator to act as a motor.

151) The method of claim 150 further comprising employing the generator as a starter motor for said prime mover.

152) The method of claim 150 further comprising
zz) sensing when the prime mover is involved in a substantially non-power producing section of its power production cycle, and,
aaa) reducing the quadrature current to below the synchronous speed of the prime mover-generator combination, during periods when the prime mover is producing substantially no power other than inertia, whereby causing the generator to power the prime mover during non-power producing periods of the prime mover.

153) The method of claim **152** further comprising employing the generator as a starter motor for said prime mover.

154) The method of claim **150** further comprising the step of

5 bbb) permitting the natural induction machine generator to motor transition during power output cyclic variations of the prime mover, whereby the generator may act as a motor during periods of low or zero power outputs of the prime mover.

10 155) The method of claim **154**, further comprising the step of employing the generator as a starter motor for said prime mover.

156) A method for controlling the output of a prime mover comprising

15 a) allowing the prime mover to vary its intake and speed and output due to variations of its torque load, and
 b) receiving signals regarding a required power output increase; and,
 c) adjusting the torque load on the prime mover so as to enable the required power output increase, and,
 d) receiving signals regarding a required power output decrease; and,
20 e) adjusting the torque load on the prime mover so as to enable the required power output decrease.

157) The method of claim **156** wherein said method further comprising the step of

25 f) during periods of operation wherein the power output of said prime mover is equal to the desired power output, maintaining the torque load on the prime mover in equilibrium with the torque output of said prime mover.

30 158) The method of claim **156** further comprising the step of

 g) determining the substantially exact torque load at which a dynamically unstable prime mover will maintain a required power output, and
 h) stopping the dynamically unstable prime mover from changing speed by
35 applying the substantially exact torque load to the prime mover upon the substantial achievement by the prime mover of the speed needed for the required power output.

159) The method of claim **156** further comprising the step of

- i) receiving signals signalling the amount by which a torque load on said prime mover is to be adjusted, and wherein said steps (c) and (e) comprising adjusting the torque load according to said signals.

5

160) The method of claim **156** wherein said step (c) comprising decreasing the torque load upon said prime mover, and wherein, said step (e) comprising increasing the torque load upon said prime mover.

10

161) The method of claim **160** wherein step (c) of causing the torque load on the prime mover to be greater than the torque output of said prime mover is accomplished by applying a predetermined torque load increment as many times as necessary until the torque load being greater than the torque output of the prime mover; and wherein step (e) of causing the torque load on the prime mover to be less than the torque output of said prime mover is accomplished by applying a predetermined torque load decrease as many times as necessary until the torque load being less than the torque output of the prime mover.

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162) The method of claim **156** further comprising

- j) sampling the difference between the actual power output of the prime mover, and a required prime mover power output, and
- k) determining a torque load to apply to said prime mover which would effect the required prime mover power output, and wherein said steps (c) and (e) comprising applying the determined torque load.

25

163) The method of claim **162** wherein said step (k) comprising applying the determined torque load in a single application in (c) and (e).

30

164) The method of claim **162** wherein steps (c) and (e) comprising applying the determined torque load in a number of small stages of changed torque load.

165) The method of claim **162** further comprising the step of

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- l) buffering the power supply to an eventual recipient of said prime mover power output during periods of power output change, so that it is not substantially adversely affected by power fluctuations during

periods of power output change.

166) The method of claim **162** further comprising the step of
m) sourcing and sinking and converting power between the prime mover and
5 an eventual recipient of the power output of said prime mover to
provide the eventual recipient with power according to the required
characteristics of the eventual recipient.

167) The method of claim **162** further not comprising the step of
10 n) substantially buffering the power supply to an eventual recipient of
said prime mover power output during periods of power output change,
whereby the eventual recipient may receive power of a somewhat
fluctuating nature during periods of power output change.

168) The method of claim **156** wherein said steps of adjusting the torque load
15 on the prime mover are done by varying a transmission between the prime
mover and a mechanical load.

169) The method of claim **156** wherein said steps of adjusting the torque load
20 on the prime mover result from varying the torque versus speed
characteristics of a load upon said prime mover.

170) The method of claim **169** wherein the method of varying a torque versus
25 speed characteristics of a load comprising varying the resistance of an
electrical load receiving power from said generator.

171) The method of claim **170** wherein step (c) comprising increasing the
30 resistance of the electrical load, and wherein step (e) comprising
decreasing the resistance of the electrical load.

172) The method of claim **171** further comprising supplying an eventual
35 electrical prime mover power output recipient with power from an auxiliary
source , and sinking power thereto, during power fluctuations caused by an
adjusted torque load

173) The method of claim **172** further comprising the step of supplying power
to the auxiliary source during prime mover operation.

174) The method of claim 173 further comprising the steps of
o) sensing or determining when the prime mover is engaged in a section
of its power output cycle in which it is substantially not producing
power, and

5 p) dynamically increasing the resistance when the prime mover is so
engaged, whereby dynamically reducing the torque load on the prime
mover.

175) The method of claim 169 wherein the torque versus speed characteristic
10 being varied by the step of

q) varying the current versus voltage characteristics of the input to an
electrical load that is receiving power from a generator that is
providing the torque load on the prime mover.

176) The method of claim 175 wherein said varying the current versus voltage
15 characteristics of the input to an electrical load, comprising

r) not allowing much or any current to flow to the electrical load below
a threshold voltage, and

20 s) at voltages above the threshold voltage, causing a steeply increasing
current ratio to flow to the electrical load, and,
wherein said steps c) and e) comprising adjusting the level of the
threshold voltage.

177) The method of claim 176 wherein said step (s) further comprising the
25 step of

t) steeply decreasing the current flow to the electrical load
substantially immediately following any drop in generator voltage,
whereby stabilizing the generator, and acting as an electronic
flywheel.

30 178) The method of claim 176 further comprising the step of starting the
prime-mover and generator, where the generator is of the type that can
operate as a motor, comprising the steps of:

35 u) sampling an input commanding system startup, and, upon receipt of a
command to start system, employing step (c), wherein step (c)
comprising:

v) synthesizing electricity of suitable voltage and current characteristics from an auxiliary energy supply so as to cause the generator to start rotating, and to rotate the prime mover.

5 179) The method of claim **176** wherein further comprising the steps of
w) sourcing power from an auxiliary power supply, and
x) providing current versus voltage characteristics that cause the
automatic transition of generator to motor action when the voltage of
the power produced by the generator is reduced due to the prime mover
10 having being engaged in a portion of its power producing cycle in
which it produces substantially no power.

180) The method of claim **179** further comprising the step of starting the
prime-mover and generator, where the generator is of the type that can
15 operate as a motor, comprising the steps of:
y) sampling an input commanding system startup, and, upon receipt of a
command to start system,
z) synthesizing electricity of suitable voltage and current
characteristics from an auxiliary energy supply so as to cause the
20 generator to start rotating, and to rotate the prime mover.

181) The method of claim **180** further comprising the step of
aa) employing a combination boost and buck converter to provide
electrical conversion in steps (c), (e), (x) and (z).

25 182) The method of claim **169** wherein the torque versus speed characteristic
of a load being varied by the step of
bb) varying the frequency of the input to an electrical load that is
receiving power from a generator that is providing the torque load on
30 the prime mover.

183) The method of claim **182** wherein said step of varying the frequency
comprising
cc) not allowing much or any current to flow to the electrical load
35 below a generator frequency threshold, and
dd) above the generator frequency threshold, increasing the current flow
to the electrical load steeply with generator frequency increase, and
wherein steps (c) and (e) comprising

ee) adjusting the level of the generator frequency threshold to control the electrical current flow to the electrical load, whereby adjusting the torque load on the prime mover.

5 184) The method of claim **183** further comprising the step of
ff) determining when the prime mover is engaged in substantially non-
power producing strokes of its power output cycle, and, during such
engagement, employing step (c), wherein said step (c) comprising
gg) decreasing the current flow to the electrical load steeply,
10 whereby acting as an electronic flywheel to the prime mover.

185) The method of claim **182** further comprising the step of starting the prime-mover and generator, where the generator is of the type that can operate as a motor, comprising the steps of:

15 hh) sampling an input commanding system startup, and, upon receipt of a command to start system,
ii) synthesizing electricity of suitable electrical characteristics from an auxiliary energy supply so as to cause the generator to start rotating, and to rotate the prime mover.

20 186) The method of claim **182** wherein further comprising the step of
jj) sourcing power from an auxiliary power supply, and
kk) providing frequency characteristics that cause the automatic
transition of generator to motor action when the voltage of the power
25 produced by the generator is reduced due to the prime mover having being engaged in a portion of its power producing cycle in which it produces substantially no power.

30 187) The method of claim **186** further comprising the step of starting the prime-mover and generator, where the generator is of the type that can operate as a motor, comprising the steps of:

ll) sampling an input commanding system startup, and, upon receipt of a command to start system,
mm) synthesizing electricity of suitable voltage and current
35 characteristics from an auxiliary energy supply so as to cause the generator to start rotating, and to rotate the prime mover.

188) The method of claim **169** wherein said step of varying the torque versus speed characteristic of a load, comprising adjusting the excitation of a generator that is powered by said prime mover, to attain steps a) and b).

5 189) The method of claim **188**, wherein said method further comprising
nn) determining a required level of generator excitation which would
achieve a torque load that would cause the prime mover to move to the
required power output, and
wherein said steps (c) and (e) comprising
10 oo) applying the determined level of generator excitation.

190) The method of claim **188** wherein said step c) comprising
pp) reducing the generator excitation, to cause an increase in prime
mover output, and
15 i) wherein said step (e) comprising
qq) increasing the generator excitation to cause a decrease in prime
mover output.

191) The method of claim **190** wherein said step (pp) comprising
20 i) reducing the generator excitation to below the synchronous speed of
the generator, where the generator is one that is capable of acting
as a motor,
and wherein said method further comprising the step of
rr) sourcing power from an auxiliary power supply, whereby causing the
25 generator to act as a motor.

192) The method of claim **191** further comprising employing the generator as a starter motor for said prime mover.

30 193) The method of claim **191** further comprising the step of charging the
auxiliary power supply during operation.

194) The method of claim **193** further comprising the step of diverting excess
produced during prime mover power output decreasing periods, to said
35 auxiliary power supply.

195) The method of claim **190** wherein said generator being an induction machine, and said steps (pp) and (qq) involve reducing and increasing the quadrature current supplied to the induction machine.

5 196) The method of claim **195** wherein said step (pp) comprising
ss) Reducing the quadrature current supplied to the induction machine,
until the synchronous speed being above the operating speed of the
generator, where the generator being configured to be capable of
acting as a motor,
10 and wherein said method further comprising the step of
tt) sourcing power from an auxiliary power supply, whereby causing the
generator to act as a motor.

15 197) The method of claim **196** further comprising employing the generator as a
starter motor for said prime mover.

198) The method of claim **196** further comprising
uu) sensing when the prime mover is involved in a substantially non-
power producing section of its power production cycle, and,
20 vv) reducing the quadrature current to below the synchronous speed of
the prime mover-generator combination, during periods when the prime
mover is producing substantially no power other than inertia, whereby
causing the generator to power the prime mover during non-power
producing periods of the prime mover.

25 199) The method of claim **198** further comprising employing the generator as a
starter motor for said prime mover.

30 200) The method of claim **198** further comprising the step of
ww) permitting the natural induction machine generator to motor
transition during power output cyclic variations of the prime mover,
whereby the generator may act as a motor during periods of low or
zero power outputs of the prime mover.

35 201) The method of claim **200**, further comprising the step of employing the
generator as a starter motor for said prime mover.

202) The method of claim **198** wherein the generator having substantially unstable torque equilibrium and further comprising the step of

- a) upon the substantial achievement by the prime mover of the commanded output increase, decreasing the synchronous speed to a synchronous speed which is part of a generator torque versus speed curve in which, at the commanded prime mover output, the torque load of the generator is equal to the torque output of the prime mover.

203) A method for controlling the output of a prime mover comprising

- a) allowing the prime mover to vary its intake and speed and output due to its torque load, and
b) receiving signals regarding a required power output increase; and,
c) adjusting the torque load on said prime mover so as to cause the required power output increase, and,
d) receiving signals regarding a required power output decrease; and,
e) adjusting the torque load on said prime mover so as to cause the required power output decrease.

204) A system comprising a generator, an engine, supplying power only to said generator, and a positive incremental load having a large increase of current draw to voltage input increase relation, over part or all of its operating range, connected to said generator, whereby said load stabilizes the operation of said engine and generator.

205) The system of claim **204** wherein said load has a limit on how much current it can draw from the generator, whereby preventing generator overload.

206) The system of claim **204** wherein said load has a threshold below which it draws little or no current.

207) The system of claim **204** wherein said generator is selected from the group consisting of direct current generators, synchronous generators, and alternating current induction generators that do not have fixed excitation frequency.

208) The system of claim **204** wherein said system further comprises energy storage connected to said positive incremental load, and wherein said

load is capable of current sourcing, and wherein said generator is capable of motor operation.

- 209) The system of claim **208** wherein said generator is selected from the group consisting of: brush comutated direct current generators, brushless direct current motors modified with suitable back diodes so as to be capable of generator operation, direct current generators having independent excitation in which the generator is caused to act as a motor by reversing the flow of armature current through the machine, induction generators configured to operate also as motors.
- 210) The system of claim **208** wherein said positive incremental load is connected to said energy storage via a boost and a buck converter.
- 211) The system of claim **208** wherein said positive incremental load is programmed to source current from the energy storage below a threshold voltage.
- 212) The system of claim **211** wherein said the threshold voltage is adjustable and further comprising an input to indicate when more or less power is required, connected to the adjustable threshold voltage, for the adjustment whereof, whereby power flow between generator and load would be altered, causing a variation in engine power output.
- 213) The system of claim **212** wherein said input comprises the position of an accelerator pedal in a vehicle, and wherein said energy storage is connected to a motor for driving said vehicle.
- 214) The system of claim **212** wherein said input comprises a reading of the depth of discharge of said energy storage, or of the rate of depth of discharge of said energy storage.
- 215) The system of claim **212** used as the source of electrical power for an off-grid electricity generation unit.
- 216) The system of claim **212** further not comprising a separate starter motor to start said engine's operation.

217) An engine, a generator connected thereto having a multiple of phases greater than 3, or preferably greater than 30, and a generator controller for varying the number and strength of poles developed in the magnetic field of the generator and thereby varying the synchronous speed of the generator, said generator controller forming a control mechanism for the power output of the engine.

218) The apparatus of claim **217** wherein said generator controller further for varying the frequency of the excitation current of said generator, for increased control over the synchronous speed of the generator.

219) An induction generator/motor, being supplied with energy by a prime mover, having a very steep torque/speed relationship about its synchronous speed.

220) The induction generator/motor of claim **219** wherein said very steep torque relationship about its synchronous speed is limited to said generator switching from maximum motoring torque to maximum generating torque and vice versa when the speed changes by less than 12 radians per second.

221) The induction generator/motor of claim **218** further comprising a generator controller for controlling the synchronous speed of the generator to vary the power output of the prime mover.

222) A method for substantially maintaining an engine's speed during power absorbing strokes of said engine, comprising connecting said engine to a generator/motor having a very high torque versus speed relationship, whereby said generator will act as a motor during power absorbing strokes of said engine, helping to maintain the engine's speed during those time periods.

ABSTRACT

An electronically controlled electrical power generator comprises a
5 generator driven by a heat engine, operated by control means, and carrying an
electrical load. Operation of the heat engine is at wide open throttle.
Control over engine operation and electrical output of the generator is
achieved by electronically manipulating the electric load, and/or adjusting
excitation levels at the generator's magnetic fields, so as to change
10 engine/generator equilibrium speed. In a beneficial embodiment, the
generator is powered by an energy storage unit, to temporarily act as a motor
and rotate the engine when starting, and during power absorbing strokes.

Figure 1.

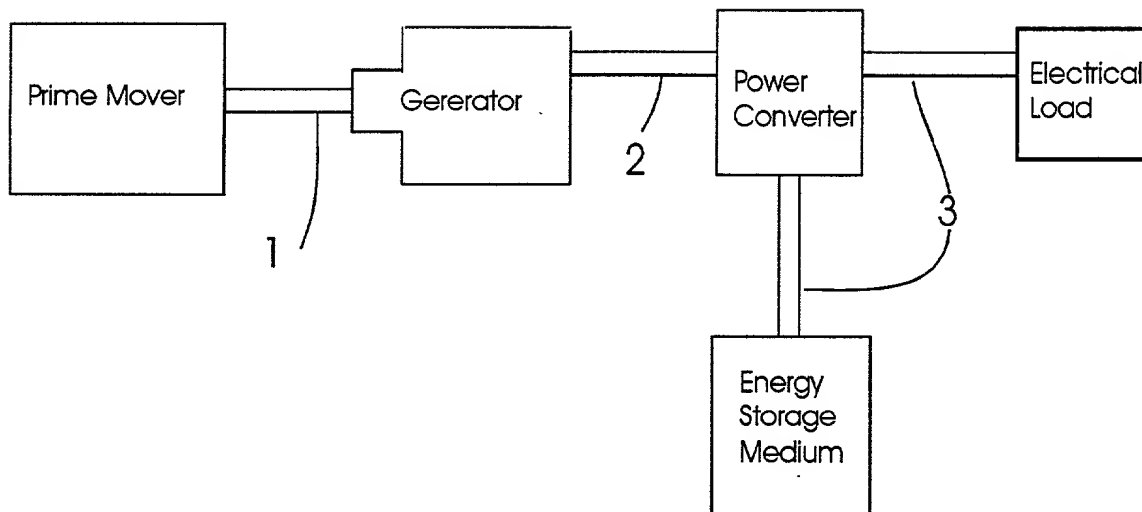


Figure 2a

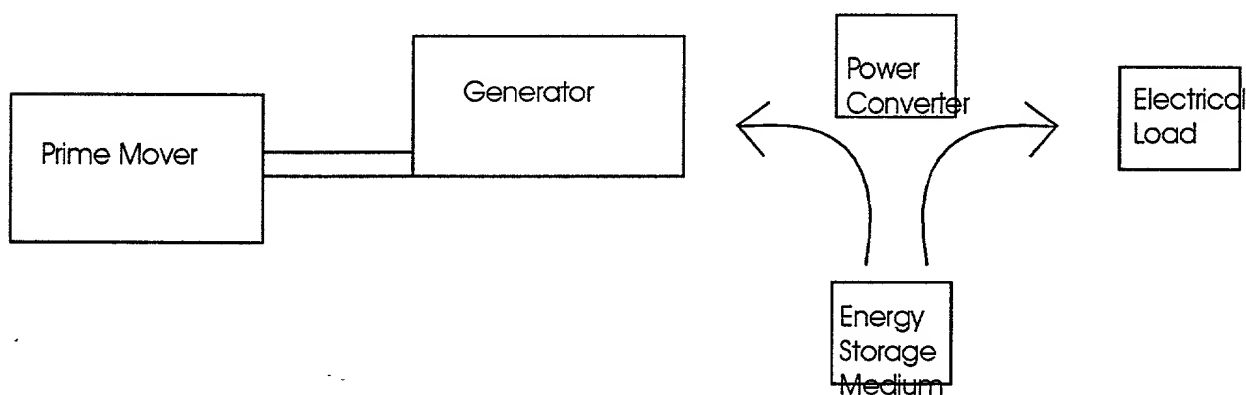


Figure 2b

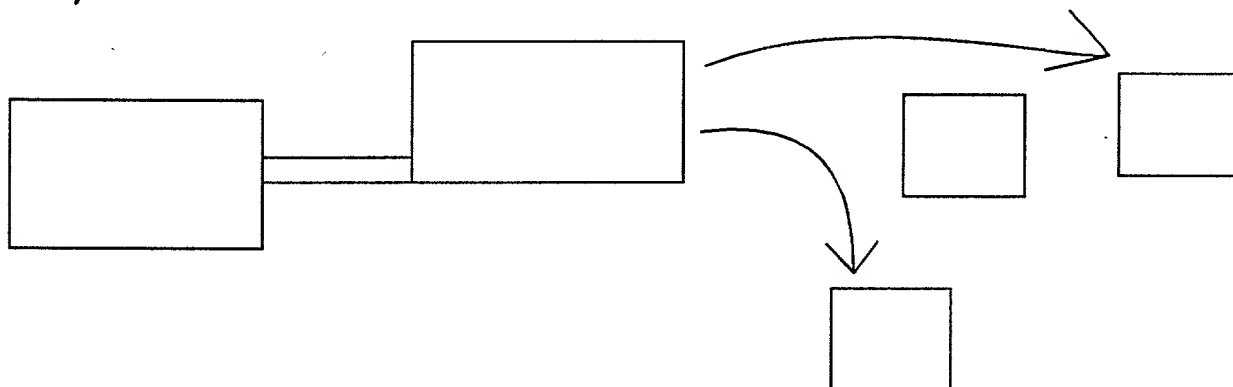


Figure 3

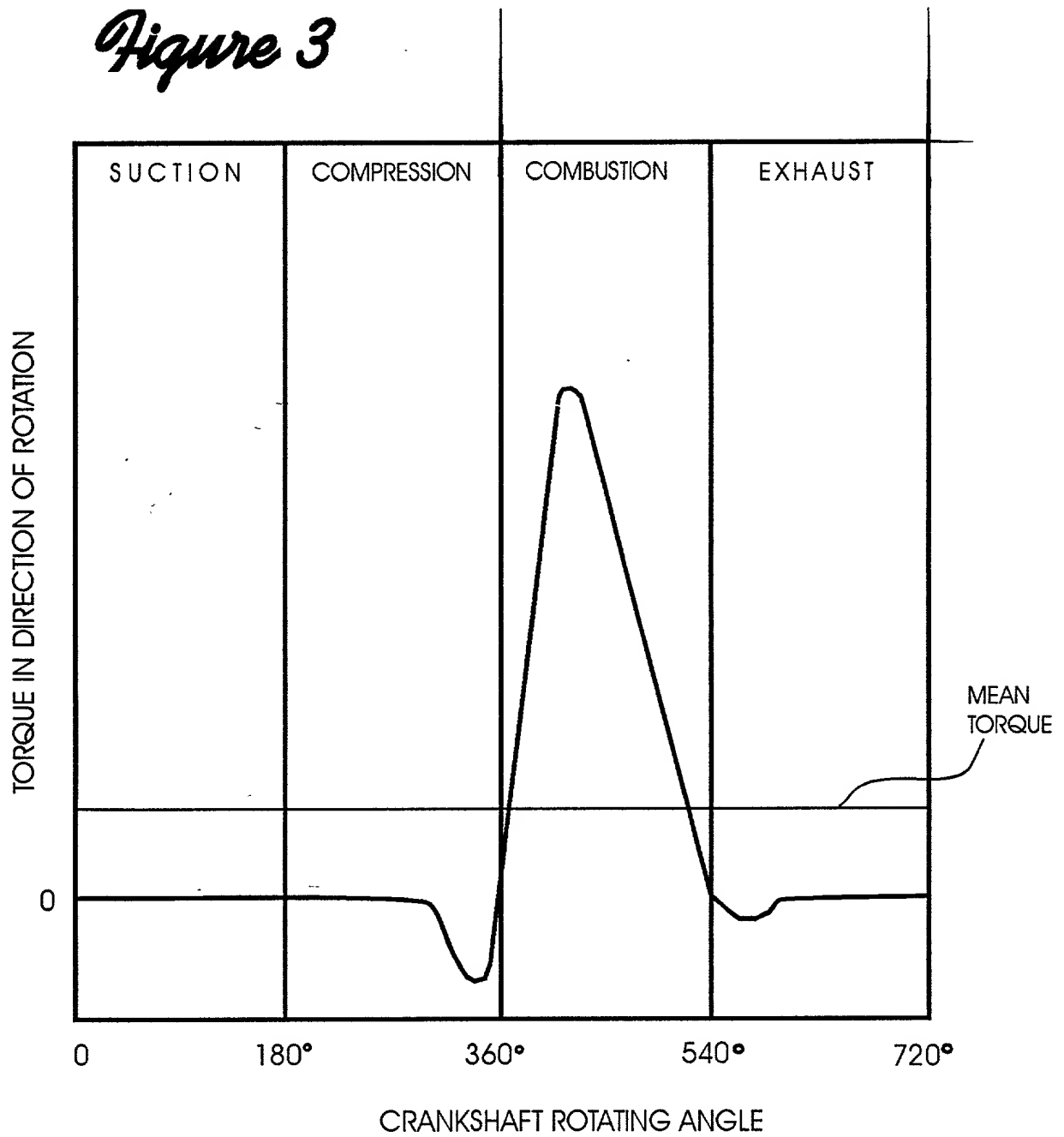


FIGURE 4

FIGURE 4

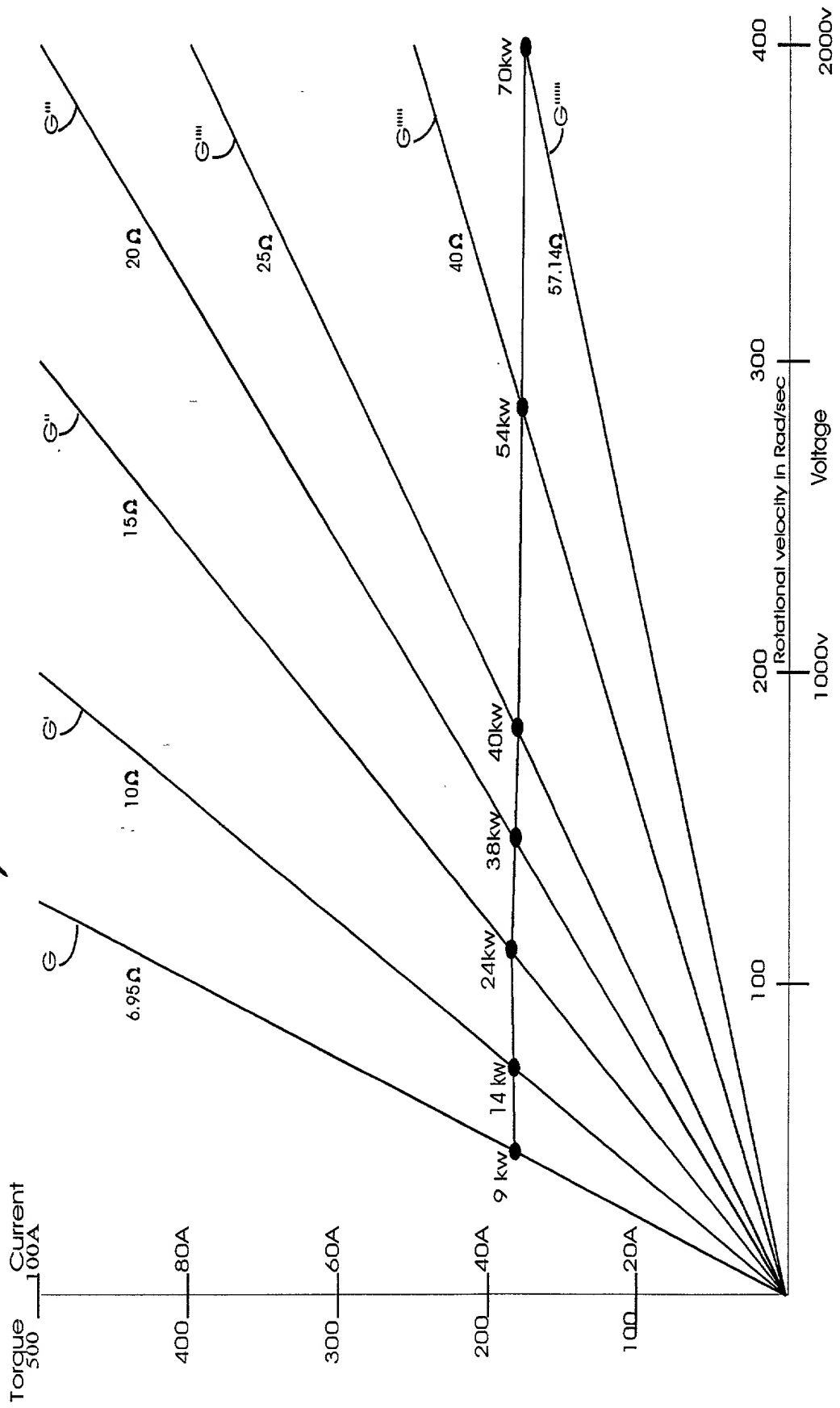


FIGURE 5

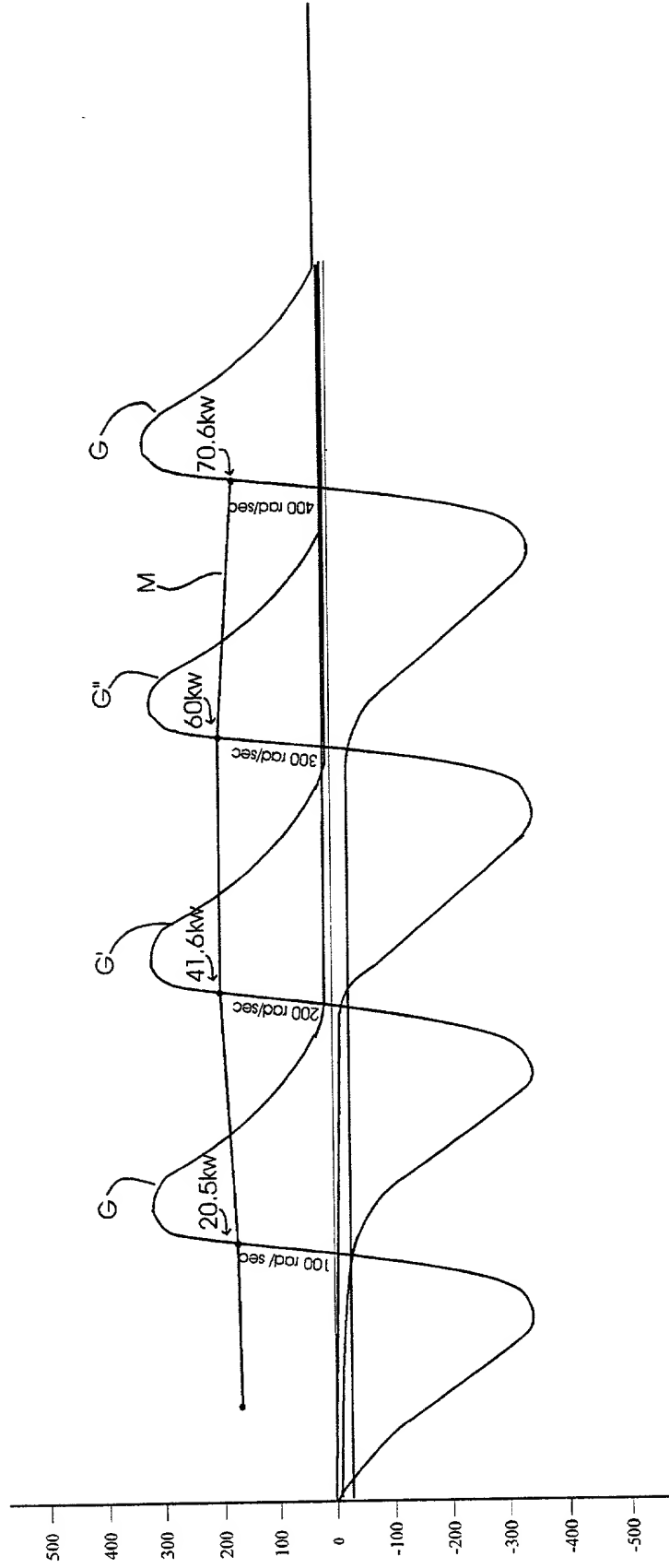


Figure 6

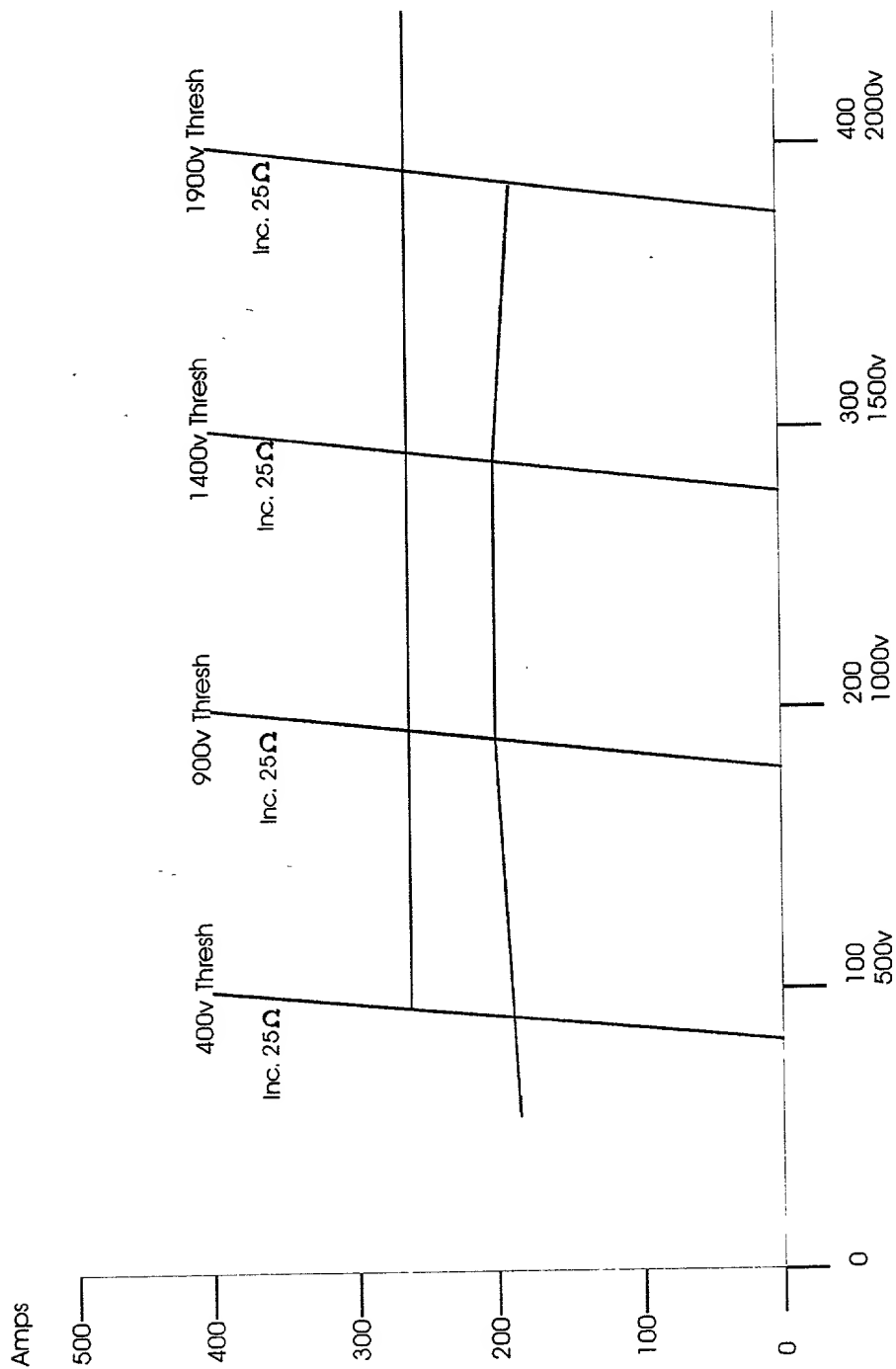


Figure 8a - Schematic of a power electronic load

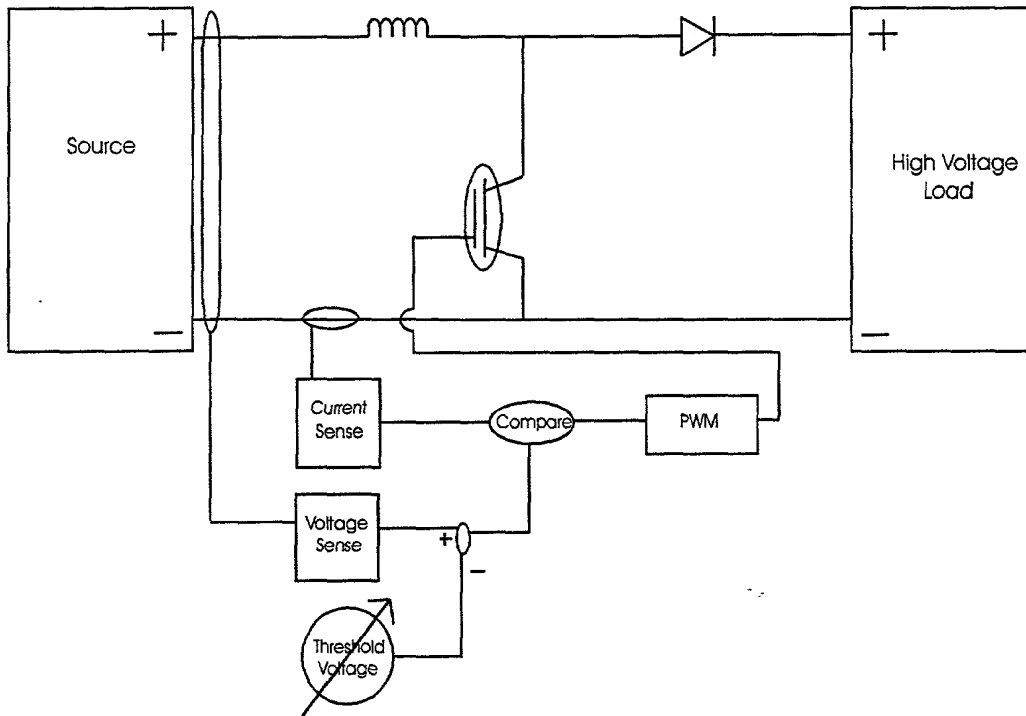
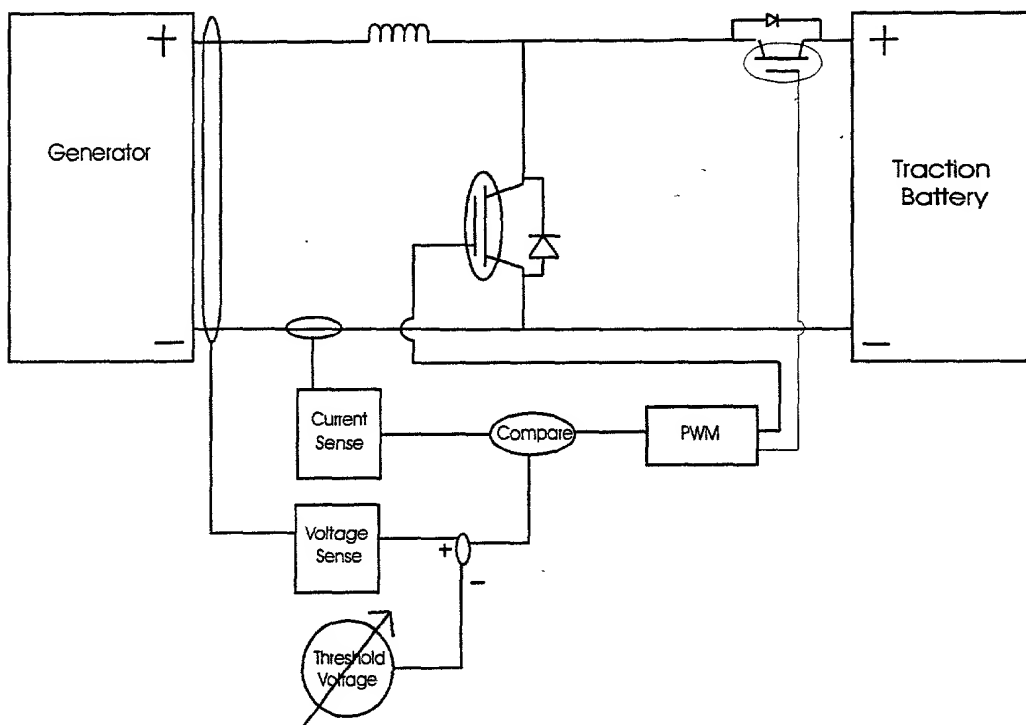


Figure 8b - Schematic of a power electronic load



*Figure 9a - an automotive alternator providing
control over the prime mover output*

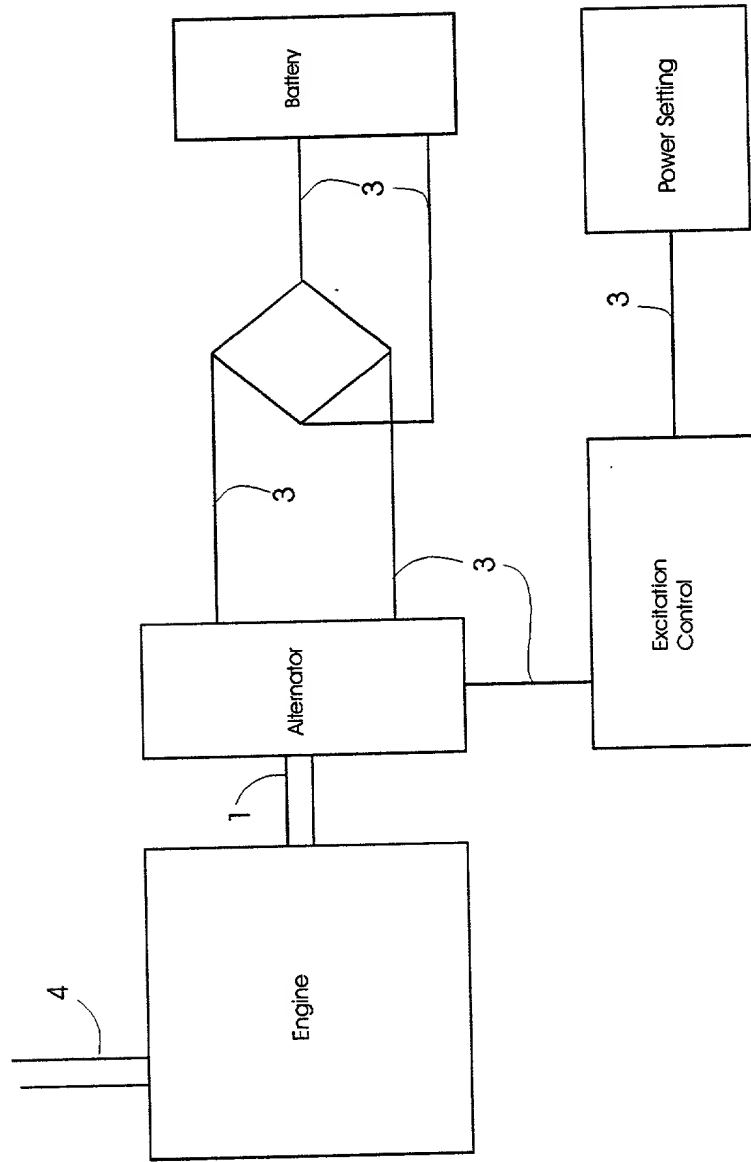
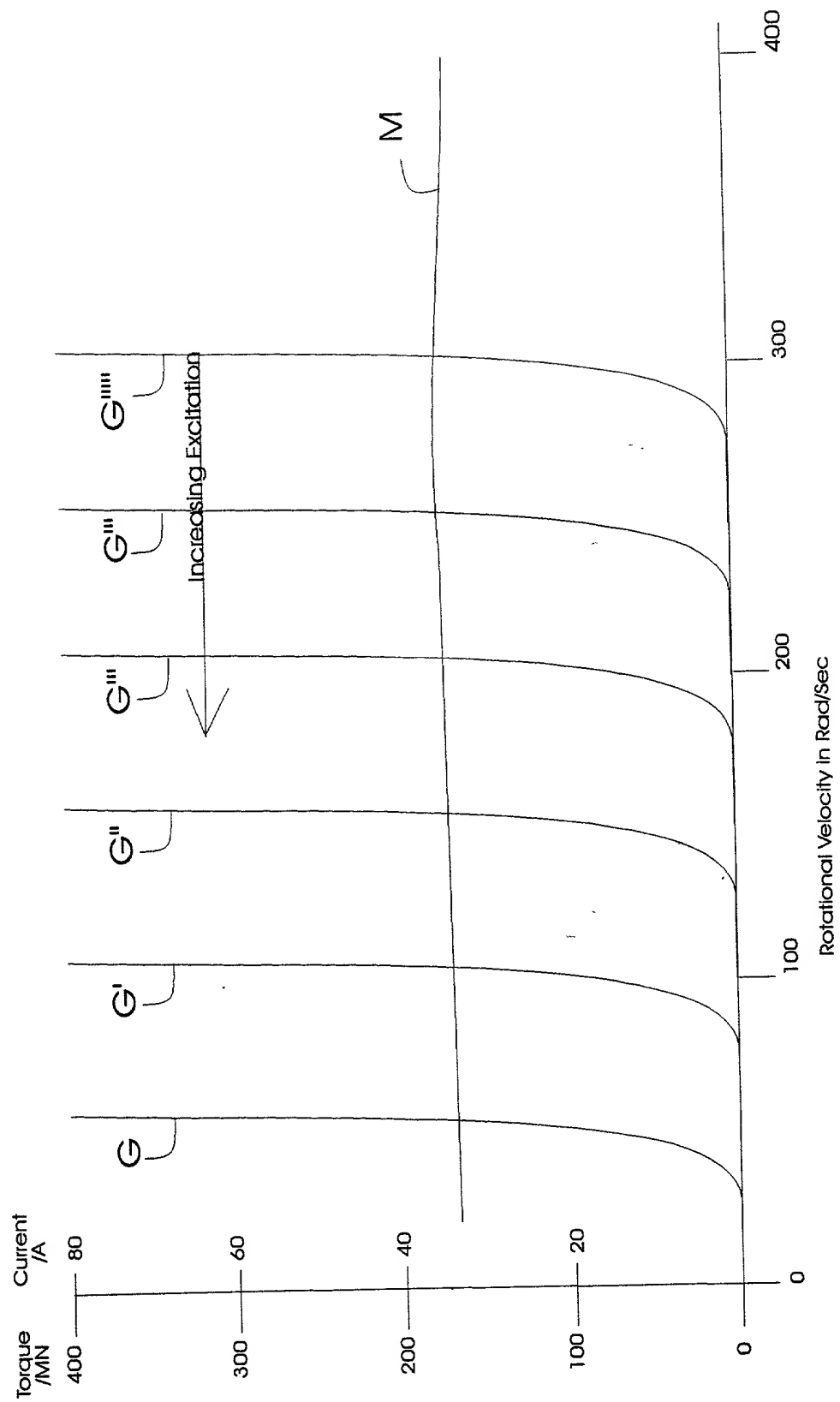


Figure 9b - the torque versus speed graph of an internal combustion engine and an alternator, supplying power to a battery, wherein the alternator has adjustable excitation.



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DECLARATION FOR UTILITY OR DESIGN PATENT APPLICATION (37 CFR 1.63)	Attorney Docket Number			
	First Named Inventor		EDELSON, Jonathan	
	COMPLETE IF KNOWN			
	Application Number		/	
	Filing Date		09/28/2000	
	Group Art Unit			
<input checked="" type="checkbox"/> Declaration Submitted with Initial Filing OR <input type="checkbox"/> Declaration Submitted after Initial Filing (surcharge (37 CFR 1.16 (e)) required)		Examiner Name		

As a below named inventor, I hereby declare that:

My residence, post office address, and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

ELECTRONICALLY CONTROLLED ENGINE GENERATOR SET

the specification of which

(Title of the Invention)

☒ is attached hereto
OR

☐ was filed on (MM/DD/YYYY) as United States Application Number or PCT International

Application Number and was amended on (MM/DD/YYYY) (if applicable).

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment specifically referred to above.

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60/156,402	09/28/1999	

[Page 1 of 2]

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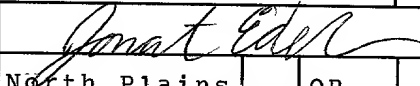
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Name	Borealis Technical Limited				
Address	23545 NW Skyline Blvd				
Address					
City	North Plains	State	OR	ZIP	97133-9204
Country	US	Telephone	503-621-3286	Fax	503-621-3425

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Given Name (first and middle (if any))		Family Name or Surname					
Jonathan Sidney		EDELSON					
Inventor's Signature			Date				
Residence: City	North Plains	State	OR	Country	US	Citizenship	US
Post Office Address	23545 NW Skyline Blvd						
Post Office Address							
City	North Plains	State	OR	ZIP	97133-9204	Country	US

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